The conservation ecology of the Dorcas gazelle (*Gazella dorcas*) in North East Libya

Walid Algadafi

A thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton for the degree of Doctor of Philosophy

April 2019

This work and any part thereof has not previously been presented in any form to the University or to any other body whether for the purposes of assessment, publication or any other purpose (unless previously indicated). Save for any express acknowledgements, references and/or bibliographies cited in the work, I confirm that the intellectual content of the work is the result of my own efforts and of no other person.

Signature:
Date: 27/ 04/ 2019

ABSTRACT

The Dorcas gazelle (*Gazella dorcas*) is an endangered antelope in North Africa whose range is now restricted to a few small populations in arid, semi-desert conditions. To be effective, conservation efforts require fundamental information about the species, especially its abundance, distribution and genetic factors. Prior to this study, there was a paucity of such data relating to the Dorcas gazelle in Libya and the original contribution of this study is to begin to fill this gap. The aim of this study is to develop strategies for the conservation management of Dorcas gazelle in post-conflict North East Libya. In order to achieve this aim, five objectives relating to current population status, threats to the species, population genetics, conservation and strategic population management were identified. These were explored using three distinct methods: questionnaires, a distance sampling field survey and genetic analysis.

The findings from both the questionnaires and the field survey indicated that there had been a significant decrease in the population in the study area compared to historical records from the 1970s. The respondents to the questionnaire estimated the decrease in the wild gazelle population to be in the range of 80% and 100% following the conflict in Libya in 2011. The responses also indicated that the main threat to the survival of Dorcas gazelle is illegal hunting and that, to reverse the decline, protected areas should be established and protection laws enforced. The respondents also believed that local communities and international conservation efforts are necessary, including captive breeding and reintroduction programmes. The findings suggested that the International Union for the Conservation of Nature (IUCN) classification of Dorcas gazelle in Libya should be revised from ‘Endangered’ to ‘Critically Endangered’ and conservation efforts increased. Questionnaire and distance sampling methods gave different population estimates at 233 and 1070 respectively, with the distance sampling results considered to be the more accurate. The genetic analysis of the sampled Dorcas gazelle population from North East Libya found eight haplotypes, four of which have not been identified elsewhere, indicating a unique genetic diversity. This suggests that, at present, there is no major risk of a genetic bottleneck.

The strategic management outcomes identified seven intervention strategies: declaration of the study area as a protected area, protection laws, awareness-raising, research and monitoring, supplementary feeding, captive breeding and international cooperation, each of theses upported by short-, medium- and long-term activities. However, achieving these requires input from local and international stakeholders and experts in a way that reflects the IUCN’s ‘One Plan’ approach.

ACKNOWLEDGEMENTS

All thanks to Allah, who guided me and illuminated the way, particularly in the difficult stages of this thesis.

I would like to thank my supervisors, Dr Christopher H. Young, Dr Lynn Besenyei and Dr Catherine M. Tobin from the Department of Biology, Chemistry and Forensic Sciences, Faculty of Science and Engineering at the University of Wolverhampton for their guidance and support through the whole PhD process, also for their guidance, support and comments on early and final drafts of this thesis. I would also like to acknowledge the tremendous support provided by Dr Joma Ifhima of the Department of Agricultural Economics, Faculty of Agriculture, Omar AL Mukhtar University, El-Beida, Libya from the inception to the completion of this thesis.

My sincerest thanks go to Omar AL Mukhtar University and the Libyan Government for generously funding this thesis, and awarding me a research studentship for fees for the duration of my study. My thanks also go to the Libyan Embassy in the UK (Cultural Attaché, London) for providing administrative support and guidance through the formal procedures.

I would like to thank Dr Husam E. M. El Alqamy from the Ministry of Forests, Land, Resource Operation, BC Canada and the Antelope Specialist Group at the IUCN, for his guidance and explanation of the DISTANCE software.

I would like to thank Dr Helen Senn of the Royal Zoological Society of Scotland who advised on the extraction and sequencing of DNA from tissue, skin and dung samples, as detailed in Chapter Seven, and facilitated access to the Wildgenes Laboratory. Additionally, I express my gratitude to Dr Simon Maddock from the Department of Biology, Chemistry and Forensic Sciences, at the University of Wolverhampton for his assistance with the DNA data analysis.

I would also like to express my gratitude to the questionnaire respondents, the experts and the hunting community for providing information and the necessary facilities to carry out this work. The cooperation of the villagers living in the study area during fieldwork and data collection is sincerely acknowledged.

Finally, I would like to thank my loving parents, my dear wife and children, my sisters and brother and friends for their unwavering support and patience throughout this entire process.

TABLE OF CONTENTS

ABSTRACT II

ACKNOWLEDGEMENTS III

TABLE OF CONTENTS IV

TABLE OF FIGURES IX

TABLE OF TABLES XII

TABLE OF PLATES XV

1. Chapter One: Introduction 1

1.1. Background to and context of the study 1
1.2. Thesis rationale and justification for the research 3
1.3. Aim and objectives 5
1.3.1. Research aim 5
1.3.2. Research objectives 5
1.4. Research questions 6
1.5. Overview of research methodology 6

2. Chapter Two: Literature review 8

2.1. Current status of antelope in Libya 8
2.2. Dorcas gazelle (*Gazella dorcas*) 8
2.2.1. Taxonomy (subspecies) and distribution 8
2.2.2. Identification and description 10
2.2.3. Habitat and diet 12
2.2.4. Reproduction 14
2.2.5. Group size and composition 14
2.2.6. Longevity 15
2.2.7. Competition and predation 15
2.3. Status of Dorcas gazelle 16
2.3.1. Global status 16
2.3.2. Status of the Dorcas gazelle in Libya 21
2.4. Attitudes and threats to Dorcas gazelle 22
2.5. Social factors in conservation: the role of questionnaires 24
2.6. Methods for estimating ungulate abundance and density 26
2.6.1. Direct methods 26
2.6.2. Indirect methods 28
2.6.3. Distance Sampling methods 30

2.6.4. Survey design 32
2.7. Genetics and conservation biology studies 32
2.8. Conservation action 38
2.8.1. Protection legislation (in Libya) 38
2.8.2. *Ex situ* and *in situ* captive breeding and reintroductions.................................39
2.8.3. Protected areas and reserves 43
2.8.4. Non-governmental organisations and private individuals involved in conservation in Libya 44
2.8.5. Strategic conservation management..45
2.9. Chapter summary 46
3. Chapter Three: Site description 47
3.1. Geographical location of the study area...47
3.1.1. Geographic and demographic information relating to Libya............................47
3.1.2. Location of the study area 48
3.1.3. The Aljasha area 49
3.1.4. The Alsrwal area 50
3.1.5. The Albulat area..50
3.2. Physical description 51
3.2.1. Geomorphology and topography 51
3.2.2. Climate and weather 51
3.2.3. Water resources 53
3.2.4. Human activities in the region...53
3.2.5. Habitats 53
3.2.6. Flora (vegetation) in the region 55
3.2.7. Fauna in the region...55
4. Chapter Four: Questionnaire surveys to investigate the perspectives of experts and in-country stakeholders regarding the conservation status of Dorcas gazelle 57
4.1. Introduction..57
4.2. Methodology 58
4.2.1. Sampling process 59
4.2.1.1. Selection of international conservation experts..60
4.2.1.2. Sampling methods for the selection of local stakeholders 60
4.2.2. Design and administration of the questionnaires 62
4.2.2.1. Experts questionnaire 62
4.2.2.2. Local stakeholders' questionnaires (In-country questionnaires)................62

4.2.3. Ethical considerations....65
4.2.4. Data analysis process....66
4.3. Results....67
4.3.1. The perspective of international conservation experts....67
4.3.1.1. Distribution and numbers of Dorcas gazelle....67
4.3.1.2. Threats to Dorcas gazelle....68
4.3.1.3. Conservation and management of Dorcas gazelle....69
4.3.1.4. Populations, threats and conservation measures concerning the Dorcas gazelle outside Libya....72
4.3.2. The perspectives of local stakeholders on aspects of Dorcas gazelle....73
4.3.2.1. Current status and population trends....74
4.3.2.2. The relationship between gazelle sightings and the variables....77
4.3.2.3. Relationship between estimates of the decrease in Dorcas gazelle numbers and the variables....79
4.3.2.4. Attitudes to hunting and reasons for the decrease in gazelle numbers....80
4.3.2.5. Assaults and gazelle killed....84
4.3.2.6. Relationship between reports of assaults on gazelle and the variables....87
4.3.2.7. Occurrence of gazelle with other animal species and preferred vegetation species (2015 survey)....89
4.3.2.8. Effectiveness of current and future conservation measures for Dorcas gazelle (questionnaire 2015)....89
4.4. Chapter summary....93
5. Chapter Five: Field surveys for the assessment of the abundance of Dorcas gazelle....95
5.1. Introduction....95
5.2. Methods....96
5.2.1. Initial survey of gazelle distribution (summer 2015)....96
5.2.2. Survey design and method for distance sampling (summer 2016)....99
5.2.3. Data recording method....104
5.2.4. The relationship between the density and abundance of dung and animal abundance....104
5.2.5. Calculation of the dung decay rate in the field....105
5.3. Data storage....106
5.4. Analysis of distance sampling data....106
5.4.1. Estimating the detection function and model fitting....108
5.5. Results....108
5.5.1. Indirect indicators of the presence of Dorcas gazelle....109
5.5.2. Direct indicators of Dorcas gazelle (sightings)....112

5.5.3. Associated fauna and wildlife 113
5.5.4. Vegetation in the sampled area 113
5.5.5. Distance sampling data analysis 114
5.5.5.1. Detection function 114
5.5.5.2. Global dung density estimates 119
5.5.5.3. Estimated dung decay rate 119
5.5.5.4. Estimate of the abundance of the Dorcas gazelle population 119
5. 6. Chapter summary 120
6. Chapter Six: Genetic diversity of Dorcas gazelle in the study area 122
6.1. Introduction 122
6.2. Materials and methods 124
6.2.1. Sample collection 124
6.2.2. DNA extraction from collected samples 127
6.2.3. Checking the quality and estimating the quantity of the DNA extracted 128
6.2.4. Molecular methods 129
6.2.5. Cytochrome b sequencing 129
6.2.6. Alignment and editing of sequences 130
6.2.7. Network building and genetic diversity testing 130
6.3. Results 131
6.3.1. DNA extraction and amplification by PCR 131
6.3.2. Cytochrome b gene from mtDNA 132
6.3.3. Haplotype network construction and genetic diversity 132
6.3.4. Genetic relationships among species 135
6.3.5. Genetic diversity within species 137
6.4. Chapter summary 138
7. Chapter Seven: Discussion 139
7.1. Overview 139
7.2. Current status and population trends 139
7.3. Threats 148
7.4. Genetic status of Dorcas gazelle in North East Libya 153
7.5. Conservation measures 157
7.6. A proposed comprehensive conservation management strategy for Dorcas gazelle in the study area in North East Libya 169
7.7. Dissemination of information 173
7.8. Chapter summary 174
8. Chapter Eight: Conclusions and recommendations 177

8.1. The main conclusions 177
8.2. Review of research aim and objectives 179
8.3. Limitations of the research...180
8.4. Recommendations...181
REFERENCES 184
APPENDICES 209
Appendix 1: List of experts to whom the questionnaire was distributed. (Respondents shown in the grey shaded areas)...209
Appendix 2: Experts questionnaire...212
Appendix 3: Cover letter for expert questionnaire 216
Appendix 4: In-country questionnaire 2015 217
Appendix 5: In-country questionnaire 2016 223
Appendix 6: Definition of the Chi-square Test and T-Test (Paired Samples Test) 227
Appendix 7: Breakdown of gazelle sightings according to location, date, number of gazelles and number of respondents 229
Appendix 8: Field sheet for summer survey 2015 231
Appendix 9: Field sheet used to collect distance sampling data 232
Appendix 10: Field sheet used to observe decomposition rate (number of Dorcas gazelle dung remaining) 233
Appendix 11: Screenshot of part of the analysis of distance data imported into the DISTANCE 7.0 programme 234
Appendix 12: GenBank accession numbers for the 90 reference samples used in this study 235
Appendix 13: The sequences of samples obtained 236
Appendix 14: Summary and critical assessment of the research findings.....................238
Appendix 15: Elements of a breeding programme...241

TABLE OF FIGURES

Fig. 1.1. Sampling locations of wild specimens of Dorcas (♦) and Saudi gazelle (O) from Lerp *et al*. (2011). The grey shaded area shows the potential distribution range of Dorcas gazelles according to IUCN antelope survey reports (East, 1988; Mallon and Kingswood, 2001). Numbers in brackets indicate number of samples obtained from each region………………………………………………**4**

Fig. 1.2. Location of survey sites in Chad, Niger and Tunisia visited during the pilot phase of the Pan Sahara Wildlife Survey 2009 to 2012……………………………………………………………......**5**

Fig. 2.1. Map of countries in which Dorcas gazelle is known to occur (IUCN, 2017)…...…..………**10**

Fig. 2.2. Location of protected and reserve areas for Dorcas gazelle…………….……………….....**17**

Fig. 2.3. Range loss for Dorcas gazelle in the Sahara……………………………………………….**18**

Fig. 2.4. Location of sightings of Dorcas gazelle reported in Misonne (1977 cited in Khattabi and Mallon, 2001), Essghaier (1980), Essghaier and Johnson (1981) and El-Alqamy and Baha El Din (2006) and their relationship with the area of the present study………………………………..…..**21**

Fig. 2.5. Dorcas gazelle detection probabilities with distance from vehicle on transect…..……….. **31**

Fig. 2.6. Detection function using pooled detections from all years..…………….…………………**31**

Fig. 2.7 a and b. Statistical parsimony network based on (a) a 412 bp fragment (73 sequences) and (b) the complete cytochrome b gene (57 sequences). Each circle represents a different haplotype, whereby circle size is proportional to the number of individuals in the data set with that haplotype (legend size represents one animal). The colour code indicates the origin of the samples (see legend). Smaller open circles represent missing haplotypes, and connecting lines correspond to one mutational step……………………………………………………………………………………**34**

Fig. 2.8. Genetic relationship among gazelles from the Southern Levant and other localities. A. Bayesian phylogenetic reconstruction………………………..………………………………………..**36**

Fig. 2.9. Median-joining haplotype network showing the relationships among Dorcas gazelle populations across the species range………………..……………………………………………………**37**

Fig. 2.10. The conservation translocation cycle (Hayek *et al*. 2016)…….…………………………**41**

Fig. 3.1. Map showing the location of Libya in North Africa. Its provinces and certain northern cities are identified in relation to the study area (based on Google Maps, 2017)………..………..…….**47**

Fig. 3.2. The study area including the Aljasha, Alsrwal and Albulat areas (created by the author using ArcGIS based on an image from Google Maps)……………………………….………………**48**

Fig. 3.3. Average climate data for the period 1950-2004 from the Benina meteorological station (El-Barasi *et al*. 2013)…………………………………………..……………………………………**52**

Fig. 4.1. Approximate locations and percentages of Dorgas gazelle sighted by respondents in the study area in both surveys 2011-2015 (n=130) and 2015-2016 (n=100).………….…………………**75**

Fig. 4.2. Approximate locations of individual gazelles sighted by respondents in the study area from 2011 to 2016 (combined data from both surveys).…..……..…………………………………………**76**

Fig. 4.3. Percentage of Dorcas gazelle sightings by place (combined data from both surveys)…...**76**

Fig. 4.4. The decline of Dorcas gazelle during the period 2011 - 2016 as estimated by respondents………………………………………..………………..……………………………**79**

Fig. 4.5. Opinions of respondents about threats and the factors that led to the decline of wildlife, including the Dorcas gazelle population, before and after the conflict in Libya which began in 2011 (answers to open question no. 7)……..……………..…………………………………………..**81**

Fig. 4.6. Prioritisation of threats to the Dorcas gazelle in the study area according to the mean scores of the responses…..……………………………………………..……………..…………..**84**

Fig. 4.7. Approximate locations of reported hunting incidents resulting in the killing of Dorcas gazelle or other species between 1964 and 2016 in Libya as a whole and in the study area………**86**

Fig. 4.8. Dorcas gazelle killings in Libya (including the study area) between 1964 and 2016 as reported by respondents……………………………………..………………………………………**86**

Fig. 4.9. Ranking of potential conservation measures that could have been used at the time of the 2015 survey, from the most to least important measures (grand means and standard errors). These are the opinions of respondents who were asked what would be the most effective Dorcas gazelle conservation measures that could be used at the present time in the Region South of Green Mountain……………………………………………………………………….…………....………**90**

Fig. 4.10. Ranking of future conservation measures from the most to least important measures (grand means and standard errors) (2015 survey). These are the opinions of respondents who were asked what would be the most effective Dorcas gazelle conservation measures that could be used in the future in the Region South of Green Mountain……………….……………………..……………**91**

Fig. 4.11. Opinions of the respondents about which organisations should have a role in the implementation and enforcement of protection measures (Question 14)……………….…………….**92**

Fig. 5.1. Locations of the three survey areas A, B and C for the 2015 field survey within the study area…………..…………………………………………………..………………………..……….**97**

Fig. 5.2. Sampling locations for the three survey areas, based on coordinates determined using the 'Research Randomizer' software (Urbaniak and Plous, 2014)………………………..…….…….**98**

Fig. 5.3. Positioning of transect bands for each survey point.………………………..…………..…**98**

Fig. 5.4. Location of high and low-density strata of Dorcas gazelle in the study region..………..…**..99**

Fig. 5.5. Approximate location of survey transects in the study areas……………………………..….**101**

Fig. 5.6. Belt transect lines of 10 m widths, showing the spacing (dotted lines) between transect segments (solid lines). Transect segments were separated by 1 km in high- and 2 km in low-density areas………..………………..………………………………..…….……………………………**101**

Fig. 5.7. Map of locations where Dorcas gazelle dung pellet groups were found in the study area………………………………………………………………………………………………**.109**

Fig. 5.8. Frequency of occurrence of each age category of dung (n = 48)……………………......**110**

Fig. 5.9. Frequency of occurrence of pellets in each group (n = 1339)…………………...………**110**

Fig. 5.10. Frequency of occurrence of the different size of areas containing dung (cm^2) (n = 48)……………………………………………………………………………………………...**111**

Fig. 5.11. Number and location of gazelles sighted in the study area, during August and September 2016…………………..…………………………………………………..……………………..**112**

Fig. 5.12. Detection probability 1. Preliminary global detection function for Dorcas gazelle dung with distance from line transects in the study area…………………………..…………..……..…………**115**

Fig. 5.13. Detection probability 2. Preliminary global detection function for Dorcas gazelle dung with distance from line transects in the study area………………………..……………………………**115**

Fig. 5.14. Detection probability 3. Preliminary global detection function for Dorcas gazelle dung with distance from line transects in the study area………………………………..……………………**116**

Fig. 5.15. Detection probability. Preliminary global detection function (high- and low-density data combined) for Dorcas gazelle dung with distance from line transects in the study area. The red line is the probability of detecting dung away from the centre of the transect (i.e. the Detection Function) and the columns are the distance bins used to group the distance observations in the modeling process of the detection function. Changing these bins can significantly affect the shape of the detection function………………………………..……………………………………………………**118**

Fig. 5.16. The dung decay rate over a period of 12 months as a percentage of the number of dung pellets remaining on the ground for plots 1 to 5. Plots 1-4 are in rugged habitat, and plot 5 is in sandy habitat.……………………………………………………………………………………………**120**

Fig. 6.1. Addition of study area sampling location to Lerp *et al*.'s (2011) map. ♦ = Dorcas gazelle and O = Saudi gazelle. (Numbers in brackets indicate the number of samples obtained, circles indicate 'groups location')…………………………………………………………………………**125**

Fig. 6.2. View of 77 bp long part of the aligned sequences. The screenshot was taken from MEGA software version 7. Sequences from DRG001 to DRG021 belong to the gazelles from North East Libya.………………………………………………………………………………………………**132**

Fig. 6.3. Statistical minimum-spanning network showing the genetic relationships among Dorcas gazelle mtDNA haplotypes from Libya and Dorcas gazelle and other gazelle species from several countries, based on a 597 bp fragment of the mtDNA cytochrome b. Each circle represents a different haplotype and the circle size is proportional to the frequency of the haplotype (number of individuals). The short lines on the connecting lines correspond to one mutational step. All samples are included in this diagram. The GenBank and Libyan samples accession numbers can be found in Table 6.2 and Appendix 12.…………………………………………………………………………**135**

TABLE OF TABLES

Table 2.1. Status of the Dorcas gazelle in the countries in its range in 2007……………..……......**19**

Table 4.1. Techniques of tests/programmes, variables and objectives…………………………..…..**66**

Table 4.2. Respondents' view of the main priority/priorities and/or opportunities for conserving Dorcas gazelle in Libya, and the viability of restoring numbers to historical levels…………………..**70**

Table 4.3. Profile of respondents for the 2015 questionnaire cohort by age group and level of education (n = 130) (uneducated = did not attend school or attended school to age11, high school = attended school until age 17, university = studied to under-graduate or post-graduate degree level)……………..………………………………………………………………………………………**73**

Table 4.4. Profile of respondents by age group and level of education (n = 100) for the 2016 questionnaire cohort…………………………………………………………………..…………….**74**

Table 4.5. T-test analysis (Paired Samples Test) of the sighting of gazelle in the periods 2011-15 and 2016………………………………………………………………………………..…………….**74**

Table 4.6. Overview of the locations of individual gazelle sightings in the wild in the study area by respondents from 2011 to 2016 (combined data from both surveys).……….……………………..**75**

Table 4.7. Estimates of gazelle group sizes as reported by respondents' (%) during the last 5 years (2011 - 2016)…………………………………………………………………………..…………**77**

Table 4.8. Responses to the question 'Have you ever seen Dorcas gazelle in the wild during the previous 4 years (2011 - 2015)?' according to educational level (Expected values derived from SPSS)……………………………………………………………...…………..…………………**77**

Table 4.9. Chi-Square to test the relationship between gazelle sightings and education level. (df is degrees of freedom)……………………………………………………………………………......**77**

Table 4.10. Responses to the question 'Have you ever seen Dorcas gazelle in the wild during the last year (2016)' according to education level (Expected values derived from SPSS)………...……**78**

Table 4.11. Category of respondents for the question 'Have you ever seen Dorcas gazelle in the wild during the previous 4 years (2011 - 2015)?' (Expected values derived from SPSS)….……….**78**

Table 4.12. Categories of respondents for the question 'Have you ever seen Dorcas gazelle in the wild during the last year (2016)'? (Expected values derived from SPSS).....................................**79**

Table 4.13. Chi-Square to test the relationship between gazelle sightings with category of respondent. (df is degrees of freedom)…………………………………………………………......**79**

Table 4.14. Estimates of the decrease of Dorcas gazelle numbers in the wild during the previous 4 years (2011 - 2015) according to age group (Expected values derived from SPSS)…...……..……**80**

Table 4.15. Chi-Square to test the relationship between an estimate of the decrease in Dorcas gazelle numbers and age group. (df is degrees of freedom)…………………………….…………..**80**

Table 4.16. Respondents' opinions about the relative importance of issues affecting Dorcas gazelle and all wildlife in the study area. Question 8, (n = 130)…………………………………………………**83**

Table 4.17. Attacks on gazelle known to the respondents that had occurred at different locations in Libya (Fig. 4.7) as reported during both surveys..……………………………………...……..**84-85**

Table 4.18. Knowledge of gazelle assaults (2015 survey) according to education level (Expected values derived from SPSS)….…...…..**87**

Table 4.19. Knowledge of gazelle assaults (2016 survey) according to education level (Expected values derived from SPSS)…………………………………………………………………....……..**87**

Table 4.20. Chi-Square to test the relationship between gazelle assaults and education level. (df is degrees of freedom)………………………………………………………………………..………..**88**

Table 4.21. Knowledge of gazelle assaults (2011 - 2015) according to category of respondents (Expected values derived from SPSS)……………………………………………………………………**88**

Table 4.22. Chi-Square to test the relationship between gazelle assaults and category of respondent (2011 – 2015). (df is degrees of freedom)…………………………..……………....….**88**

Table 4.23. The occurrence of Dorcas gazelle in association with other animal species. However, 30% of the respondents had no information regarding the association of Dorcas gazelle with other animal species (2015 survey)……………………………………………..………………..…….**89**

Table 4.24. Preferred vegetation of the Dorcas gazelle in the study area (2015 survey)…..………**89**

Table 4.25. Opinions of respondents regarding which conservation measures that could be used at the present time would be effective for the conservation of the Dorcas gazelle in the study area...**90**

Table 4.26. Opinions of respondents on the likely effectiveness of future conservation measures for Dorcas gazelle……………..……………………………………………………………………..….**91**

Table 4.27. Respondents' views of the main priority/priorities and/or opportunities for conserving Dorcas gazelle in the study area, and the viability of restoring numbers to historical levels (2015 survey)…………………………………………………………………………………………..**93**

Table 5.1. Terrain/substrate and habitat categories used in this study..…………………….……**103**

Table 5.2. Estimation and description of gazelle dung age…….…………….………….……..**103**

Table 5.3. Definition of column variables which were imported into the DISTANCE 7.0 software..**106**

Table 5.4. The number and percentage of sites in the study area at which indicators of the presence of Dorcas gazelle were recorded (n = 250)……………….…………………………**109**

Table 5.5. Summary of sightings of Dorcas gazelle, during August and September 2016…..……**112**

Table 5.6. Summary of fauna recorded along the entire transect surveys (Estimated numbers), during August and September 2016………………………………………………….…………**113**

Table 5.7. Dominant plant species at 250 recording sites, during August and September of 2015 and 2016…………………………………………………………………………..……………..**113**

Table 5.8. Detection Fct/Global/Chi-sq GOF Test 1. Interval cut points used to fit detection function……………………………………………..…………………………………………**114**

Table 5.9. Detection Fct/Global/Chi-sq GOF Test 2. Interval cut points used to fit detection function…………………………………………………..…………………………………….**114**

Table 5.10. Detection Fct/Global/Chi-sq GOF Test 3. Interval cut points used to fit detection function…………………………………………………..……………………………………**114**

Table 5.11. Key functions used to fit detection function in the study area……………………..……**116**

Table 5.12. Half-normal/cosine key. Model fit parameters and point estimates for the field detection function (Estimate of the detection probability)………………………...……………………………**116**

Table 5.13. Fit parameters comparing detection function using CDS and MCDS in the study area……………………………………………………………………………………..……….**117**

Table 5.14. Detection Fct/Global/Chi-sq GOF Test. Intervals cut points used to fit detection function…………………………………...………………………………………………………**118**

Table 5.15. Half-normal/cosine key. Model fit parameters and point estimates of field detection function (Estimate of the detection probability)…………………………………...………………**118**

Table 5.16. Half-normal/cosine. Dorcas gazelle dung density/abundance estimates……………..**119**

Table 6.1. Origin of wild and captive gazelle samples collected from Libya for use in DNA genetic analysis…………………………………………………………………………………………**125-127**

Table 6.2. List of identical sequences created using PopArt software. The table combines data from samples in the literature (Lerp *et al*. 2011 and Godinho *et al*. 2012) with samples from the present study area. N/A = data not available. The data from the Libyan samples (beginning DRG) are shown in the grey shaded areas together with samples from other countries which have the same haplotype. The table excludes samples that have a unique haplotype. This information is shown in diagrammatic form in Fig 6.3……………..………………..……………………..…………………..**133-134**

Table 6.3. The differentiation of the samples of Libyan Dorcas gazelle populations into eight haplotypes………………………………..…………...………………...……………………….……**136**

Table 6.4. Estimates of genetic diversity for the species of gazelle based on a 597bp mitochondrial fragment……………………………………..………………………………………………………**137**

Table 7.1. A proposed comprehensive conservation management strategy for Dorcas gazelle in the study area in North East Libya……………………………..………………………………..**171-173**

TABLE OF PLATES

Plate 2.1. Phenotypes of Dorcas gazelle (Castello, 2016)………..………………………………..….**11**

Plate 2.2. Photos revealing the slaughter of Dorcas gazelle (left) and the presence of Arabian sand gazelles (right) imported into Libya (SCF, 2012)……………………………………………..……….**23**

Plate 2.3. Hunting activities from vehicles in Libya (SCF, 2012)….………..………………………….**23**

Plate. 2.4. Slender-horned gazelles killed in southern Tunisia (SCF, 2012)…………...………….**24**

Plate 2.5. Motorbike and quad bikes which are capable of chasing down and exhausting wildlife over difficult terrain (SCF, 2012)…………………………………………………………….………….**24**

Plate 3.1. The Aljasha area in the summer - September 2016 (Photos: Walid Algadafi)………..…**49**

Plate 3.2. The main shrubs in the Aljasha study area (Photos taken in August and September 2016 by Walid Algadafi)………………………………………………………………….…………………….**50**

Plate 3.3. The main shrubs in the Alsrwal study area (Photos taken in August and September 2016 by Walid Algadafi)……………………………………………………………………..………………..**50**

Plate 3.4. The Albulat area (Bulat Alraml) in September 2016 (Photos: Walid Algadafi)……...……**51**

Plate 3.5. Temporary wetlands in the Wadi El Mahaga with little egret (*Egretta garzetta*) photographed during the survey of the study area (August and September 2015. Photos: Walid Algadafi)……………………………………………………………………………………………...**53**

Plate 3.6. Habitats photographed during the survey of the study area, August and September 2016. a: a wadi; b: hilly terrain with rocks and boulders; c: a transitional, semi-desert landscape; d: desert terrain with *Cyperus conglomeratus* (Photos: Walid Algadafi)……………………………………...**54**

Plate 3.7. A selection of plant species photographed during the survey of the study area (August and September 2015) (Photos: Walid Algadafi)………..…….…………………………………………**56**

Plate 5.1. Field team: an observer, a recorder (the author) and assistants in the study area (2016)…………………………..…………………………………………………………………………**102**

Plate 5.2. Reducing number of pellets in dung deposits in Plot 1 in a rugged area.……………….**106**

Plate 5.3. Dorcas gazelle paths, tracks and hoof prints observed in the study area……………….**108**

Plate 5.4. Physical indications of the presence of Dorcas gazelle in the study area in the form of butchered remains left by hunters (August and September 2016)………….……………..…..….**111**

Plate 6.1. Samples of Dorcas gazelle (skin/head) from the wild habitat in the study area………..**124**

Chapter One: Introduction

1.1. Background to and context of the study

The Dorcas gazelle (*Gazella dorcas*) is a small, slender antelope, well adapted to living in desert, arid or semi-arid environments in North Africa (Abaigar *et al*. 2018). The Dorcas gazelle is an important part of the natural heritage of Libya. Hufnagl (1972, p. 52) described the gazelle as "the living embodiment of the romantic desert". He goes on to say that in many places there are songs about the beauty of the gazelle, which is particularly apparent in comparison with "the monotony and grandeur of the desert".

According to many scholars, including Rands *et al*. (2010) and Stork (2010), the world is losing the biodiversity vital for the survival of the human race faster than ever before. Some scholars have estimated that approximately 40 % of current species will be extinct by 2050 (Saatoğlu, 2015). The International Union for the Conservation of Nature (IUCN) has demonstrated that 47,677 species are at risk of extinction globally, but it is estimated that a mere 26% of recognised species have been evaluated against the criteria for the IUCN's Red List of Threatened Species (IUCN, 2017). With regard to antelopes, Price and Gittleman (2007) estimated that 62% of antelope populations are decreasing worldwide and that 50% of antelope species face extinction.

The Dorcas gazelle previously had the most extensive distribution of any African gazelle, but it no longer exists in several of its former areas (Frost, 2014). Lerp *et al*. (2011) likewise state that numbers continue to decrease and the populations which remain are more scattered than they were even at the end of the last century. The IUCN (2017) claimed that the decline was estimated to be more than 30% over a period of about 15 years up to April 2016 and that fewer than 25% of those remaining at that time lived in protected areas. This suggests that there was still a large proportion (75%) that needed to be protected. The Dorcas gazelle is currently classified as globally 'Vulnerable to Extinction' by the IUCN (Stabach *et al*. 2017).

Across its range in Africa, the Dorcas gazelle has faced decline. In Senegal, it was considered to be extinct from the mid-1970s until it was reintroduced in 2007 (Abaigar *et al*. 2013). In Mauritania, Burkina Faso and Nigeria, its status is not known, and it may be extinct in these countries (Frost, 2014).

Durant *et al*. (2014) stated that in recent years, the Sahara has experienced a significant reduction in its fauna. Magurran and Dornelas (2010) argued that a number of species in the region have already become extinct as a result of anthropogenic factors and many more will disappear in the coming years. Newby *et al*. (2016) stated that, in this region, such factors include overhunting, habitat loss and desertification. Attacks on wildlife by humans is one of the most common forms of wildlife extermination, drastically reducing wildlife numbers and even leading to their local or global extinction which can potentially result in significant environmental losses. The extent and frequency of such human-wildlife conflicts is of major concern in conservation (Conover, 2002; Woodroffe *et al*. 2005).

According to Gilbert (2011), a major cause of species loss can be attributed to declines in genetic variation often resulting from inbreeding, which is manifested in reduced birth rates and/or an increase in the rate of death. In such circumstances, species lack the genetic variation to adapt to changing conditions in the environment and no longer have the potential to evolve (Gilbert, 2011).

There have been reports of declining numbers throughout Libya over the past 60 years. According to Essghaier (1980) Dorcas gazelle occured in Libya in herds of a hundred or more in the 1960s, whilst Hufnagl (1972) reported that a herd of forty was exceptional by 1972. By 2001, Dorcas gazelle were classified as ‘Endangered’ in Libya in the IUCN Red List, following a Global Survey of Antelopes conducted by the Antelope Specialist Group (Mallon and Kingswood, 2001). In 2011, conflict broke out in Libya, part of a wave of violence that swept across parts of North Africa and the Middle East known as ‘the Arab Spring’. Since the beginning of this conflict in Libya, precise information relating to the distribution and numbers of Dorcas gazelle has become even more difficult to obtain.

Scholte and Hashim (2013) estimated that the total population in Libya was unlikely to exceed 1,000 individuals. However, precise information on the current distribution and numbers of the species is lacking and the situation in Libya remains uncertain.

A preliminary questionnaire study was conducted by the current author in 2007 and published in 2017 (Algadafi *et al*. 2017) on the status of Dorcas gazelle in North East Libya. This indicated that, whilst they were still present, sightings of Dorcas gazelle had decreased in the study area south of the Green Mountain in North East Libya and in the neighbouring Libyan desert by between 60% and 90% compared to historical estimates. It emphasised the need for an urgent follow-up study.

In the Saharan region in general, there has been little rigorous scientific research, partly because the region is very large and politically unstable (Stabach *et al*. 2017). Most of the extant data is circumstantial or produced by conflating incomplete records from different years and large areas (Stabach *et al*. 2017). This supports the need for more surveys and studies of lesser-explored regions, such as Libya. This study contributes to filling that gap for the study area in North East Libya.

1.2. Thesis rationale and justification for the research

This research addresses a specific gap in global knowledge about the distribution, abundance, conservation and genetics of the Dorcas gazelle in North East Libya. The effects of the changing conservation threats to this species in Libya have never been investigated due to the challenging geopolitical and logistical context. The study results will be used to inform future conservation management strategies for the Dorcas gazelle, both within, and potentially beyond, Libya. As such, it makes an original contribution to current knowledge and understanding.

This research can be justified by the need for up-to-date information in three vital areas: the status of the Dorcas gazelle in Libya, its genetic characteristics and an understanding of appropriate conservation actions.

Status of Dorcas gazelle in Libya: The Dorcas gazelle is currently classified as '*Endangered*' in Libya (Mallon and Kingswood, 2001; Scholte and Hashim, 2013). However, precise information on the current distribution and numbers of the species in Libya is lacking and the situation remains uncertain. A review of population studies from across its distribution range by the IUCN (2017) concluded that population declines are continuing. This study contributes to filling that gap in the study area.

Genetic analysis of Dorcas gazelle in Libya: Lerp *et al*. (2011) attempted to provide a phylogeographic framework for the conservation of Saharan and Arabian Dorcas gazelles. They obtained gazelle samples from across its range (Fig. 1.1), but not from Libya. They concluded that, in order for the framework to be more complete, Dorcas gazelles from Libya should be included. This study seeks to extend the phylogeographic knowledge of Dorcas gazelle in Libya through an analysis of its haplotypes.

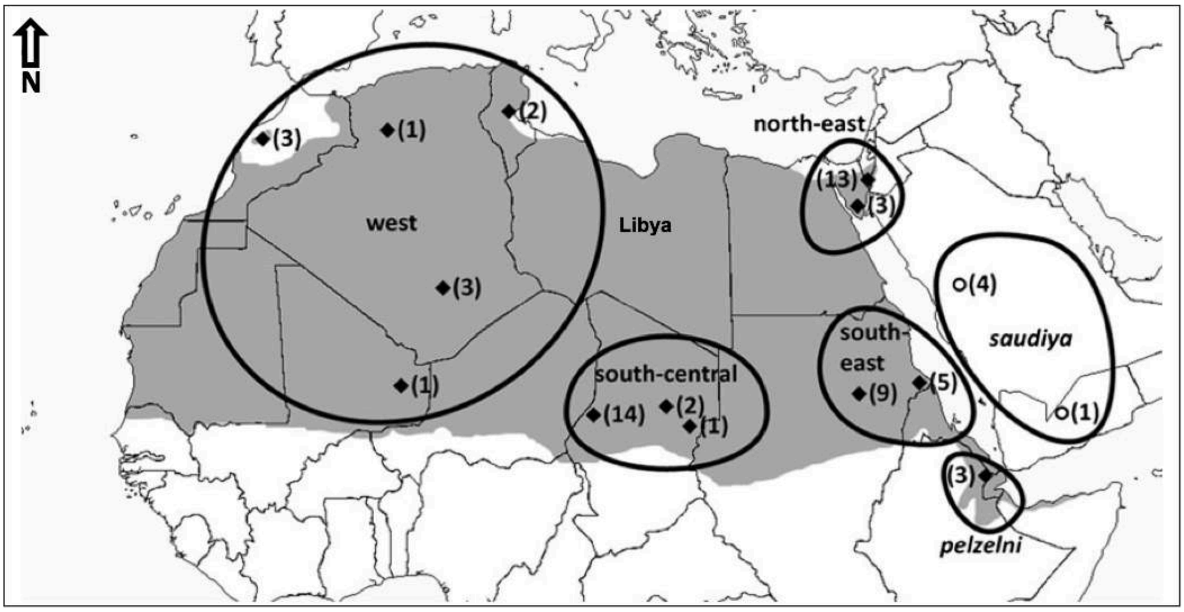


Fig. 1.1. Sampling locations of wild specimens of Dorcas (♦) and Saudi gazelle (O) for genetic analysis from Lerp *et al*. (2011). The grey shaded area shows the potential distribution range of Dorcas gazelles according to IUCN antelope survey reports (East, 1988; Mallon and Kingswood, 2001). Numbers in brackets indicate number of samples obtained from each region.

Conservation actions: There are a limited number of protected areas in Libya (a total of 8 protected areas, reserves and national parks, according to Khattabi and Mallon, 2001; Scholte and Hashim, 2013). However, there are no protected areas or conservation programmes specifically for Dorcas gazelle within the study area. There have been a number of plans to increase the protected areas in the country. The Libyan Wildlife Technical Committee had planned to establish a network of protected areas in the southern parts of the country (Khattabi and Mallon, 2001). The Sahelo-Saharan Interest Group of the Sahara Conservation Fund (SSIG, 2003) also developed conservation plans for parts of Libya. Neither of these projects was ever implemented.

Wacher and Newby (2012) reported on the pilot phase of the Pan Sahara Wildlife Survey (PSWS), instigated by the Sahara Conservation Fund, which operated from 2009 - 2012. This project led to a range of collaborations aimed at improving the conservation of little understood, but at risk, wildlife in the Sahelo-Saharan region. However, none have yet been reported. The programme plan submitted with the original PSWS proposal called for surveys in Niger, Chad and Tunisia (as shown in Fig. 1.2). However, Libya was not included, and this seems to have been a significant omission.

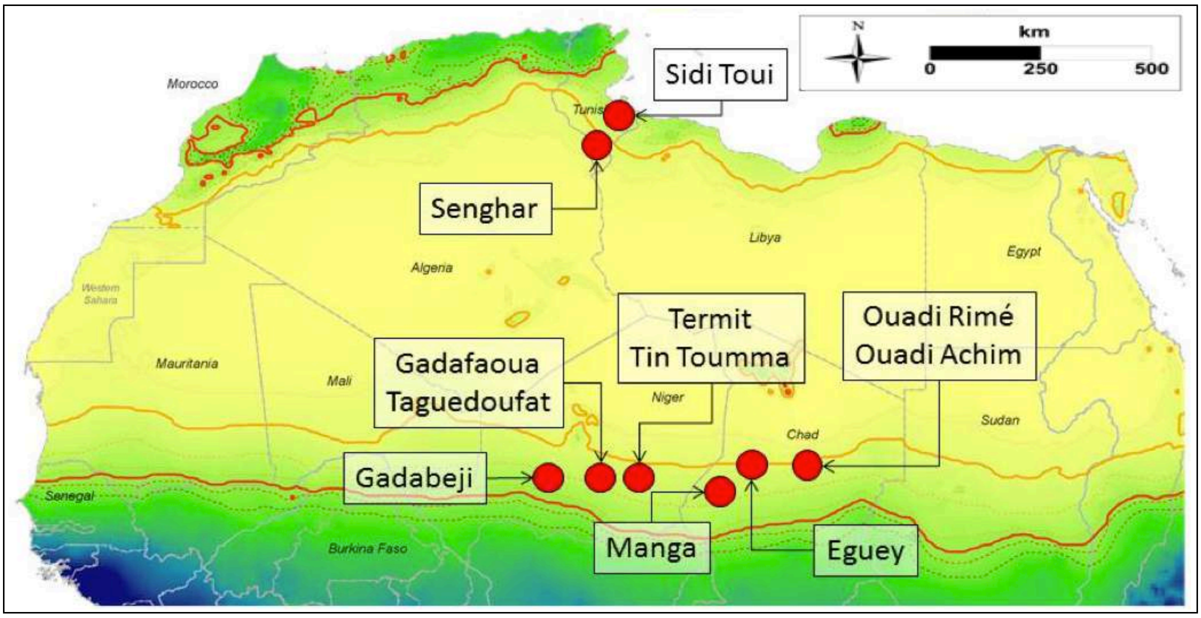


Fig. 1.2. Location of survey sites in Chad, Niger and Tunisia visited during the pilot phase of the Pan Sahara Wildlife Survey 2009 to 2012 (Wacher and Newby, 2012)

There is therefore a lack of research into appropriate conservation actions and the implementation of conservation policy in Libya. The present study is important because it comes in the period following the Libyan Revolution of 2011. It seeks to identify the elements of an appropriate and effective conservation stategy for the Dorcas gazelle in North East Libya and evaluate where such strategies could have wider impact.

1.3. Aim and objectives

1.3.1. Research aim

The aim of this study is to develop strategies for the conservation management of Dorcas gazelle in post-conflict North East Libya.

1.3.2. Research objectives

To achieve the aim, the following objectives were identified:

1. To evaluate the current situation relating to the population of Dorcas gazelle in North East Libya, in the area south of Green Mountain, using a combination of questionnaires and field surveys.
2. To investigate the threats to the population of Dorcas gazelle in North East Libya through the use of questionnaires for different interest groups.
3. To contribute to an understanding of the conservation genetics of Dorcas gazelle in North East Libya through DNA analysis of field samples.

4. To identify key policy initiatives in the conservation of the Dorcas gazelle in North East Libya by integrating the perspectives of international experts, local stakeholders and existing published data.
5. To propose a strategy for the conservation of the Dorcas gazelle in the study area by combining the outcomes of the three lines of investigation with existing data.

1.4. Research questions

Based on the above aim and objectives, this study attempts to answer the following research questions:

1. What is the estimated abundance of Dorcas gazelle in the study area?
2. Has the continuing war in Libya, which began in 2011, contributed to a decline in the population of the Dorcas gazelle in North East Libya?
3. Does a lack of environmental awareness by and the general behaviour of local residents lead to practices that endanger the Dorcas gazelle?
4. Is the population of Dorcas gazelle in the study area genetically distinctive?
5. What are the elements of a suitable management strategy that will have a positive impact on the conservation of Dorcas gazelle in North East Libya?

1.5. Overview of research methodology

In order to gain a greater insight into various key issues relating to the conservation ecology of the Dorcas gazelle (*Gazella dorcas*) in North East Libya, this study used three research methods: questionnaires, field surveys and genetic analysis. The adoption of these three research methods can be justified because they enable fundamental data about the species to be collected, especially about its abundance, distribution, main threats and genetic factors. Such information, Bro-Jorgensen and Mallon (2016) argue, is essential if conservation efforts are to be effective. Detailed information about these methods is given in chapters 4, 5 and 6 respectively.

The mixed-method approach has been adopted in this study. Tashakkori and Creswell (2007, p. 4) defined the mixed-method approach as

> research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or program of inquiry.

The mixed-method approach is useful because it allows a researcher to use different data collection methods to improve the validity of the data collected (Collis and Hussey, 2003; Saunders *et al*. 2009).

Denscombe (2008) stressed that using more than one method has the advantage of providing a fuller or more complete picture about the issue that is being studied. Bryman (2006) stated that both quantitative and qualitative approaches can be integrated at different stages of the research process: formulation of research questions; sampling; data collection and data analysis. The conclusions drawn as a result of using a mixed methods approach can improve the quality of the research (Gorman and Clayton, 2005).

The combination of three methods of data collection also facilitated triangulation of both methodology and data to provide robust and reliable evidence (Lincoln and Guba, 2000). According to Denzin (2010), methodological triangulation involves the use of multiple qualitative and/or quantitative methods for investigating an issue, while data triangulation uses dissimilar sources of data or different data from the same source to examine the same issue. The research presented here comprises both qualitative and quantitative approaches combined with analysis of existing academic literature and datasets to explore the emergent issues from different perspectives.

The use of a range of research methods, all of which complement each other, allows greater confidence that the outcomes will be robust and reliable and that the proposed conservation strategy for Dorcas gazelle in North East Libya will be effective.

Chapter Two: Literature review

2.1. Current status of antelope in Libya

In the global survey of antelope published in 2001 by the IUCN (Khattabi and Mallon, 2001), six species of antelope were reported in Libya:

- Scimitar-horned oryx (*Oryx dammah*) - widespread in the past but extinct at that time.
- Addax (*Addax nasomaculatus*) - last confirmed record in the middle of the 1960s with occasional reports more recently.
- Bubal hartebeest (*Alcephalus buselaphus buselaphus*).
- Dorcas gazelle (*Gazella dorcas*) - declining since the 1960s but widely present in small scattered groups.
- Slender-horned gazelle (*Gazella leptoceros*) - always rare and declining since the 1960s, although exact status uncertain.
- Dama gazelle (*Gazella dama*) - always rare and restricted to the extreme south of the country.

2.2. Dorcas gazelle (*Gazella dorcas*)

2.2.1. Taxonomy (subspecies) and distribution

Dorcas gazelle (see Plate 2.1 on p. 11) belongs to the Bovidae family, subfamily Antilopinae, and genus *Gazella*. According to Wilson and Reeder (2005), it was first described by the Swedish Zoologist Carl Linnaeus in 1758. A number of scholars, including Rostron (1972), Alados (1987), Groves (1969, 1981) and Yom-Tov *et al*. (1995) described six subspecies from different regions of its distribution range based on phenotypic variations. However, Kingswood *et al*. (2001) questioned the validity and distribution of most of these subspecies. Lerp *et al*. (2011) found no evidence from phylogeographic analysis for any distinctive geographic pattern of the genetic structure of the species and this calls into question the validity of the suggested subspecies.

The IUCN (2017) found that, in order to validate the existence of these subspecies, further studies which use molecular techniques are necessary and therefore they did not recognise any subspecies. Baldus (2009) recognized *G. d. dorcas, G. d. isabella, G. d. littoralis* and *G. d. pelzelnii,* but not *G. d. osiris* as sub-species of Dorcas gazelle. Kingdon (2016) did not recognize the Isabelline gazelle (*G. d. isabella*) as a subspecies of *Gazella dorcas*. Haltennorth and Diller (1997) considered Pelzeln's gazelle (*G. pelzelni*) to be a species in its own right (Wilson and Reeder, 2005; Frost, 2014) and they also referred to several subspecies from Arabia and Asia. The taxonomic treatment of the Dorcas gazelle requires further clarification and investigation (Frost, 2014; Castello, 2016).

Taking all this evidence together, the most recent study by Castello (2016) considers the following to be subspecies of Dorcas gazelle (*Gazella dorcas*): Egyptian Dorcas gazelle (*Gazella dorcas dorcas*), Isabelline gazelle (*Gazella dorcas isabella*), Moroccan Dorcas gazelle (*Gazella dorcas massaesyla*), Saharan Dorcas gazelle (*Gazella dorcas osiris*) and Eritrean Dorcas gazelle (*Gazella dorcas beccarii*).

According to Frost (2014), the Dorcas gazelle has had the largest distribution of any African gazelle, covering most of North Africa, including the Sahara and the Sahelian region. Wilson and Mittermeier (2011) and Scholte and Hashim (2013) concur that the Dorcas gazelle is the only extant gazelle species that can be considered to be widespread in North Africa. The native distribution of Dorcas gazelle included parts of Algeria, Burkina Faso, Chad, Djibouti, Egypt, Libya, Mali, Mauritania, Morocco, Niger, Sudan, Syria, Eritrea, Ethiopia, Israel, Senegal, Yemen, Jordan and Tunisia (Beudels *et al*. 2006). However, by the time of Frost's study in 2014, populations were scattered and no longer existed in large parts of their former range. Fig. 2.1 shows the most recent map of the distribution of the Dorcas gazelle by the IUCN (2017) and includes most, but not all, of these countries. However, its current distribution in these countries is believed to be fragmented (Wilson and Mittermeier, 2011; Scholte and Hashim, 2013).

Tchernov *et al*. (1986) suggested that the paleogeographic data indicate that the range of the Dorcas gazelle has spread out from North East Africa through a process of 'competitive exclusion', and it replaced other species such as the mountain gazelle (*Gazella gazella*) in Sinai and southern Israel.

Fig.2.1. Map of countries in which Dorcas gazelle is known to occur (IUCN, 2017)

2.2.2. Identification and description

Abaigar *et al*. (2018) describe the Dorcas gazelle (Plate 2.1) as small, slender and, well adapted to living in desert or arid environments. They state that it is smaller than the Dama or slender-horned gazelles, being 55 - 65 cm at shoulder height. The length of its head and body reaches 90 - 110 cm and the tail length is 15 - 20 cm. According to Hufangl (1972), it usually weighs 15 - 20 kg, but in captivity it frequently reaches a weight of up to 25 kg. He notes that wild specimens in Libya rarely exceed 18 kg whereas in other countries they have been known to weigh up to 20 kg (Abaigar *et al*. 2018).

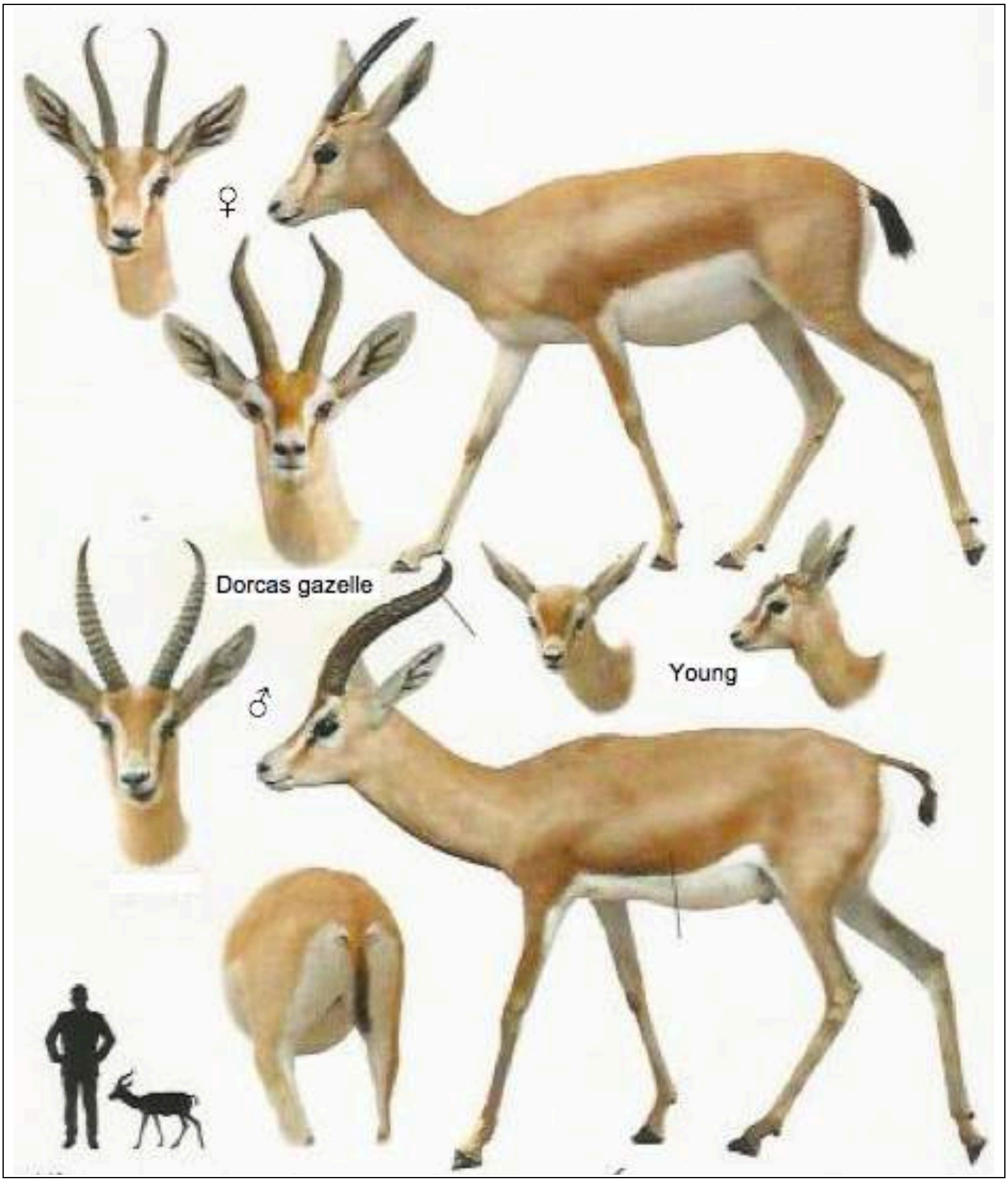


Plate 2.1. Phenotypes of Dorcas gazelle (Castello, 2016)

The upper pelage is a pale beige or sandy red, with the undersides and rump white. There is a wide rufous stripe along the lower flank between the front and rear legs, separating the white belly from the upper coat. A similarly coloured stripe occurs on the upper hind legs, creating a border for the white rump. The head has the same beige colour as the body. Additionally, there is a white eye ring, and a pair of white and dark brown stripes running from each eye to the corners of the mouth. The forehead and bridge of the nose is a light reddish tan in colour and old males may develop a fold of skin across the bridge of their nose (Castello, 2016).

Both sexes have horns. In males these are bent sharply backward, curved upward at the tips and ringed almost to the tips, with a length of 25 - 38 cm. The greatest horn length ever recorded was 38.1 cm. The horns in females are much thinner, straighter, and shorter, with fewer rings, and are 15 - 25 cm in length (Castello, 2016; Kingdon, 2016).

2.2.3. Habitat and diet

Grassland, shrub and semi-desert are the main habitats used by the Dorcas gazelle throughout its range (Chammem *et al*. 2008) and it is described as "*a habitat generalist*". Cuzin (2003) and Lafontaine *et al*. (2005) previously stated that arid and semi-arid areas are its preferred habitats, but it eschews large areas of dunes and extremely dry habitat, prefering flat rocky areas with little vegetation (Cooke *et al*. 2016). It is able to move from one area to another according to the season in order to benefit from small areas with rich forage and high levels of moisture (East, 1999). The species has been observed to prefer 'wadis', dry valleys with some vegetation, especially those dominated by *Acacia* sp. during the dry season and upland habitat during the cold season (Baharav, 1980). In Libya, according to Hufnagl (1972) Dorcas gazelle occur in a variety of dry open habitats, but they seem to greatly prefer dry watercourses or wadis with some vegetation.

On the other hand, no seasonal variation was found in habitat preferences in a study by Abaigar *et al.* (2013) which examined the habitat preferences of Dorcas gazelle in Senegal. Evidence of Dorcas gazelle, as indicated by the presence of tracks, was related to exploratory activity, with more tracks being found on the plains or plateaux rather than in the other habitats such as forest clearings or grassy clearings. Their findings suggest that, in an area where food and water are available, the structure of the habitat is the most significant factor in the Dorcas gazelles' choice of habitat.

A further consideration that may influence habitat choice by the Dorcas gazelle is their modes of communication. Abaigar *et al.* (2013) found that the Dorcas gazelle uses visible rump patch patterns for communication in different situations and this is easier in open areas.

Faecal microhistological analysis has shown that the diets of males and females in the same area are similar (Ghobrial, 1974). Many previous studies suggest that *Acacia* trees are the preferred food source of the Dorcas gazelle. For example, Attum and Mahmoud (2012) found that the most frequented trees were *Acacia* trees, even though *Balanites aegyptiaca* was the most common species in their study area in Egypt. In Sudan, Ghobrial (1974) also noted that Dorcas gazelle prefer *Acacia* leaves. However, there are no *Acacia* trees in the area of this study in North East Libya.

Attum *et al*. (2006) found that Dorcas gazelle will also make opportunistic use of any tree, irrespective of its size. This is to be expected in view of the scarcity of vegetation in the dry season. They found that gazelles use shorter trees to browse on leafy vegetation. They browse at a range of heights from close to the ground to the top of the tree.

It has been reported that Dorcas gazelle also browse on shrubs and they have been observed to eat annual grasses and forbs when available (Baharav, 1980; 1982; Grettenberger, 1987). According to Loggers (1992), gazelles in North Africa eat more shrubs and forbs than grasses during the dry season, even though these account for only 26% of the available vegetation. He suggested that this was because dicotyledonous plants contain higher levels of protein than grasses during the dry season. However, in Palestine, Baharav (1980) reported that Dorcas gazelle greatly favour grasses at times when the rain has caused fresh growth. Grettenberger (1987) identified 405 plant species that were consumed by Dorcas gazelle in the Aïa and Ténéré National Nature Reserve in Niger. *Mareua crassifolia* leaves and the shrub *Leptadenia pyrotechnica* were the preferred food, although the major part of the diet consisted of the trees *Acacia tortilis* and *Balanites aegyptiaca* and the forb *Chrozophora brocchian*. Herds can range over large areas in search of food, and they tend to congregate in areas where recent rainfall has led to fresh plant growth (Baharav, 1980). Dorcas gazelle contributes to the correct functioning of ecosystems through its role as a major disperser of seeds (Yom-Tov *et al*. 1995).

Interestingly, in the Western Sahara, El-Alqamy (2003) noted that the rumen material of adult gazelle contained larval locusts (*Shistocerca.* sp) at a proportion of 10% for males and 50% for females. This was undoubtedly a supplement to their diet of plants.

Attum and Mahmoud (2012) found that charcoal production from *Acacia* trees has a negative impact on gazelle populations because it reduced the availability of food and refuges. Furthermore, the social behaviour of Dorcas gazelles may be affected by the loss of large trees. Attum *et al*. (2006), and Wronski and Plath (2010) reported that Dorcas and other gazelles prefer larger *Acacia* trees for their dung midden sites. This may be because larger trees are more conspicuous and so advertise their presence more effectively. Protecting the Dorcas gazelle may incidentally contribute to the protection of *Acacia* populations and *vice versa* (Attum *et al*. 2006).

With regard to water requirements, several authors, including Tear *et al.* (1997) and Ostrowski and Williams (2006), have reported that certain Dorcas gazelle populations can survive without access to drinking water provided they are able to find vegetation with adequate moisture. However, a study by Attum *et al.* (2014) into the effects of precipitation patterns on Dorcas gazelle in various locations in Egypt found that some Dorcas gazelle may not be able to survive long periods of drought. Ghobrial (1974) commented that even though it is a true desert species, the capacity of the Dorcas gazelle to survive a total lack of water may be limited at times of excessive heat. This finding suggests that conservation programmes in desert areas should give consideration to the unpredictable patterns of precipitation and support corridors that enable the Dorcas gazelles to move to areas with more precipitation (Attum *et al.* 2014).

2.2.4. Reproduction

El-Alqamy (2003) stated that reproduction can occur at any time of the year, but it usually happens when forage begins to return after the rainy season. During mating, the dominant male chases off all the other males from the herd. Later, they are, in turn, chased off by pregnant females. As a result, herds of one sex are a common occurrence (Castello, 2016).

According to Dittrich (1968), the gestation period for Dorcas gazelle is usually 169-174 days. However, in Libya, it is about 164 days (Hufnagl, 1972). The period when the female is on heat is very short, only a half to two days. Most births take place between March and May. For seven days, the mother and the calf do not venture far, and it is during this period that young gazelles are susceptible to predation, especially by jackals in Libya (Hufnagl, 1972). Fawns are weaned at about 2 to 3 months of age (Loggers, 1992; Castello, 2016).

2.2.5. Group size and composition

Hufnagl (1972) reported that, in Libya, Dorcas gazelle live for most of the year in small herds containing two to eight individuals, with one of the males being dominant. The greatest coming together of Dorcas gazelle occurs at the beginning of the cold season, when herds comprise adult males and females as well as subadults. If herds are unable to congregate in the breeding season, the adults do not receive the stimulation necessary to commence the pre-mating rituals. Despite this behaviour, even as early as 1972, Hufnagl found it very unusual to find a herd of 40 individuals, although, previously, herds of 50 to 60 had frequently been encountered.

2.2.6. Longevity

Dittrich (1972) found that the maximum recorded life span of Dorcas gazelle in the wild is 12 - 13 years whereas ages up to 17 years were seen in captivity. Castello (2016) concurs with this but Mendelssohn and Yom-Tov (1987) found that the longevity of Dorcas gazelle in captivity was only up to 15 years.

2.2.7. Competition and predation

Dorcas gazelle share their habitat with livestock and humans. Attum and Mahmoud (2012) stated that Dorcas gazelles were likely to experience competition in the form of exploitation by humans and interference from competing livestock. Attum (2007) and Attum *et al*. (2009) also found that humans contribute to competition. Gazelles regard humans as predators (Grettenberger, 1987) and they may avoid large trees frequented by farmers and livestock. Stabach *et al*. (2017) also found that Dorcas gazelle tend to avoid areas of human activity.

Chammem *et al.* (2008) found that the distribution of Dorcas gazelle in Tunisia, a country which neighbours Libya, was more affected by human activities than habitat features, particularly the intensity of land transformation for agriculture. They also found that Dorcas gazelle tend to inhabit the same areas as camels, which could be due to the fact that both species use agriculture-free land for grazing.

The natural predators of gazelle have been identified by Frost (2014) and Castello (2016) as lion (*Panthera leo*), leopard (*Panthera pardus*), cheetah (*Acinonyx jubatus*), wild dog *(Lycaon pictus*), sand cat (*Felis margarita*), striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), fox (*Vulpes vulpes*), wolf (*Canis lupus*), booted eagle (*Aquila pennata*), Verreaux's eagle (*Aquila verreauxii*) and caracal (*Caracal caracal*). Of these, the only known wild predator which exists in Libya is the jackal. Jackals are particularly adept at taking the newly-born animals and they are often found close to the herds during the birthing season (Frost, 2014).

2.3. Status of Dorcas gazelle

2.3.1. Global status

Based on comprehensive revews of previous studies, East (1999), Lafontaine *et al*. (2005) and Lerp *et al*. (2011) have stated that the Dorcas gazelle was once common throughout Pre-Saharan North Africa. However, they report that its numbers declined by at least 20% in the 1990s but do not indicate how they came to that figure. As a result, its status on the IUCN Red List was changed from Least Concern/Near Threatened to Vulnerable (Laurance, 2013; Durant *et al*. 2014; Stabach *et al*. 2017; Abaigar *et al*. 2018). Abaigar *et al*. (2018) reported that the Dorcas gazelle has been under pressure for some time across its range, with numbers now being significantly lower and the populations more fragmented than was the case a few decades ago. They attribute this mainly to uncontrolled and illegal hunting and overhunting, in combination with poaching from vehicles and the destruction, degradation or loss of habitat from overgrazing by domestic livestock and human competition. Other scholars have identified other causes, including repeated droughts (Ryder, 1987; Beudels *et al*. 2006; Attum and Mahmoud, 2012) and predation by feral dogs (East, 1999). In Libya, specific up to date information is sparse but the decline is exacerbated by a lack of awareness of the value of the Dorcas gazelle (Algadafi *et al*. 2017). However, the high birth rate, its small size and its successful adaptation to dry conditions enable the Dorcas gazelle to survive droughts, habitat degradation and hunting better than other species of sympatric antelope (East, 1999).

The IUCN (2017) stated that the decline in the number of Dorcas gazelle is continuing and it is estimated that numbers have reduced by over 30% in three generations (about 15 years). Fewer than 25% of the remaining animals live in protected areas (Lerp *et al*. 2011). Although the Dorcas gazelle continues to exist in most of its former range countries, it has now disappeared from Senegal and perhaps also Nigeria, where it was considered to be extinct from the mid-1970s until it was reintroduced in 2007 (Abaigar *et al*. 2013, 2018). Its continued existence in Mauritania and Burkina Faso is not clear, and it may be extinct in these countries (Frost, 2014). Egypt has also witnessed a similar decline in population for the reasons listed above (Saleh, 1987), with the largest populations occurring in the south-eastern desert (El-Alqamy and Baha El Din, 2006). According to Frost (2014), the largest populations of Dorcas gazelle at that time were found in Chad (especially in the Ouadi Rime-Ouadi Achim Fauna Reserve), Niger (Air-Tenere National Nature Reserve and the Termit Massif-Tin Toumma desert) (see Fig. 2.2), with an estimated population of 1,500 - 2,000, and in the northern parts of the Horn of Africa. However, Wacher and Newby (2010) warned that the future of these populations was not secure as no active form of support was in place. The only countries where the distribution and abundance of gazelle may have increased are Mali and Ethiopia, where UNEP/CMS (1999) reported a population of several hundred in protected areas.

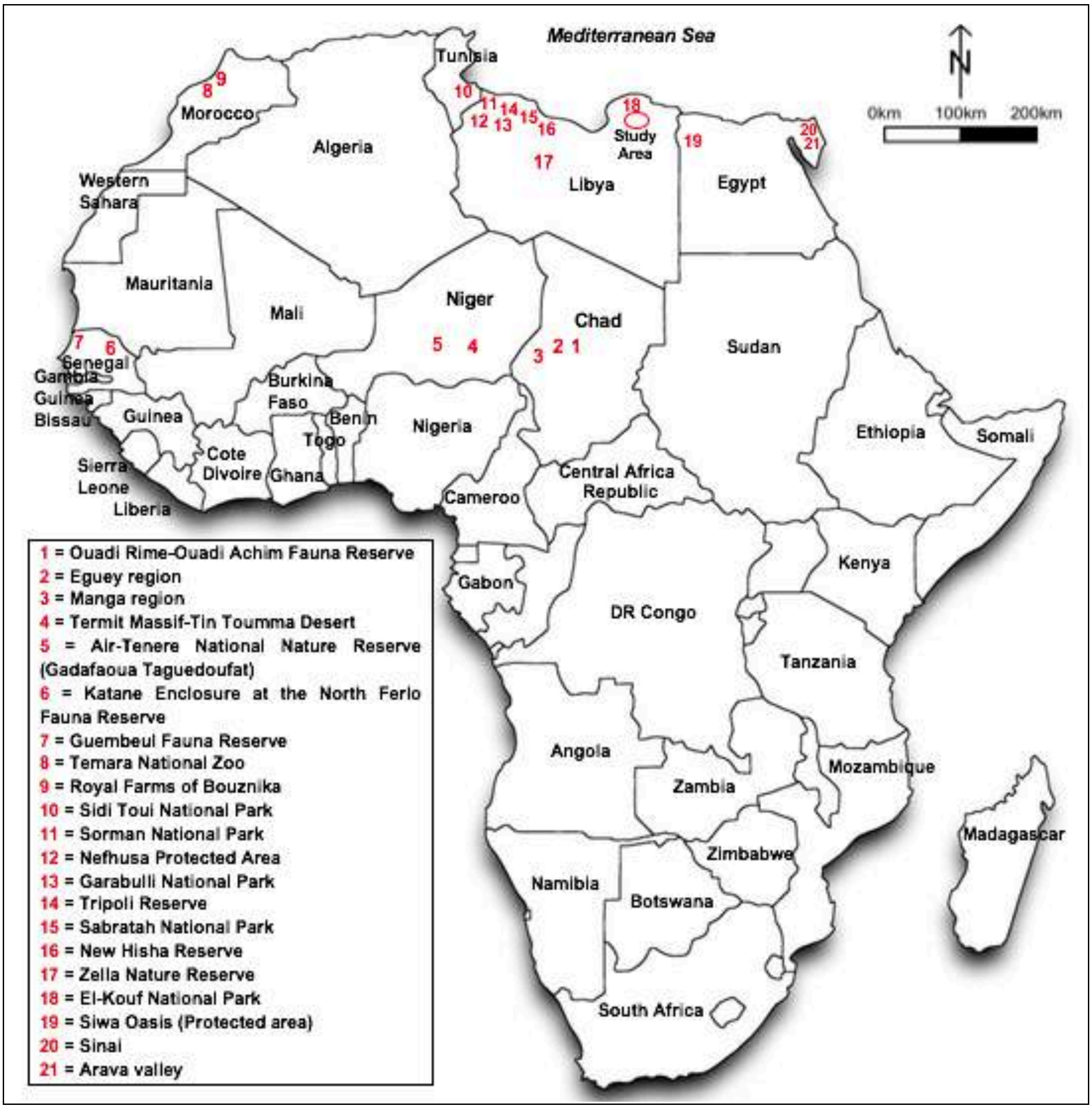


Fig. 2.2. Location of protected and reserve areas for Dorcas gazelle (adapted from Khattabi and Mallon, 2001; El-Alqamy and Baha El Din, 2006; Chammem *et al.* 2008; Lerp *et al*. 2011; Godinho *et al*. 2012; Wacher and Newby, 2012; Abaigar *et al*. 2018)

The Dorcas gazelle is the only African antelope species whose range extends into the Middle East and Asia and it is also the most common antelope throughout much of its range. Nonetheless, overhunting is drastically reducing its numbers over large areas and within the region. Mallon and Kingswood (2001) reviewed a number of surveys of Dorcas gazelle and assessed the populations as 'Endangered' in Jordan and Libya, 'Vulnerable' in Algeria, Egypt, Morocco, and Tunisia and 'Rare' in Israel.

Overall, Durant *et al*. (2014) estimated that, in the Sahara region, the Dorcas gazelle no longer inhabited 86% of its former range (Fig. 2.3). However, the estimated distribution may not be complete and should be treated with caution. For example, it does not indicate a resident population in the area of the present study in North East Libya although it is known that Dorcas gazelle was present in that area at that time (Algadafi *et al*. 2017).

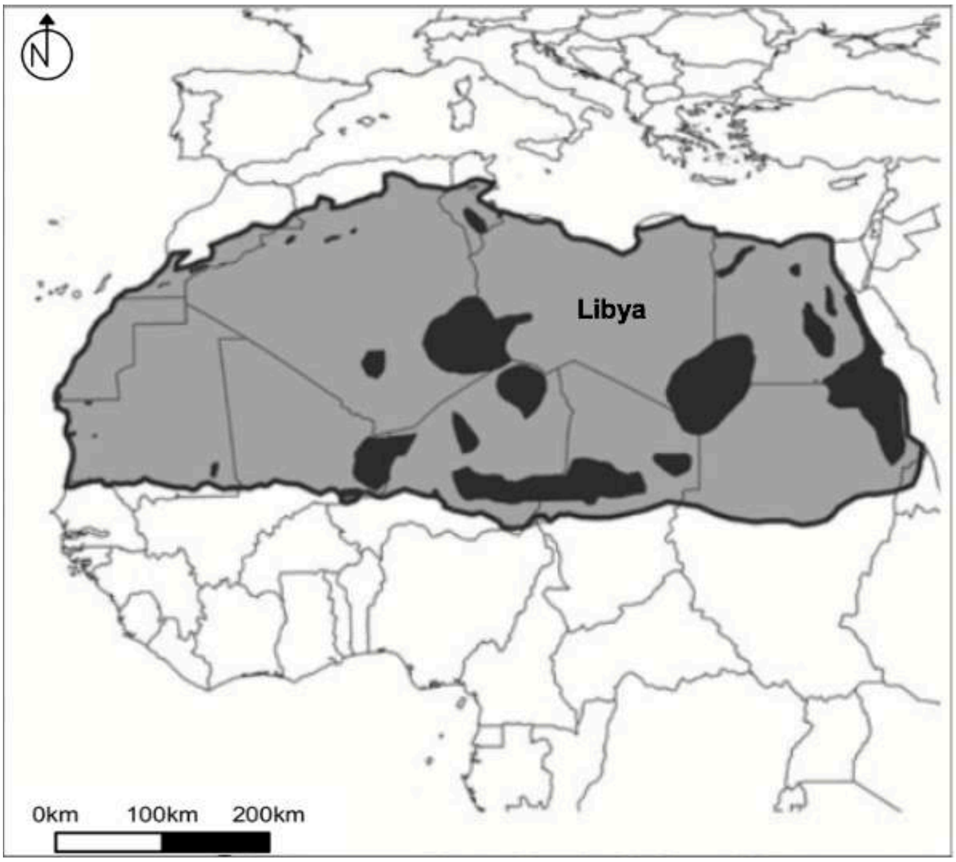


Fig. 2.3. Range loss for Dorcas gazelle in the Sahara. Grey shading = Historical range. Black shading = Resident range (adapted from Durant *et al*. 2014)

East, (1999 p. 245) estimated the global population of Dorcas gazelle at "tens of thousands" with 35 - 40,000 in Sahelo- Saharan Africa. This estimate was based on ground and aerial surveys and a full list of the studies used to arrive at the estimate is given in Appendices 3 and 4 of East (1999). However, it appears that most of the studies were conducted only in protected areas. According to Frost (2014), the most recent global estimate suggests that there are around 40,000 individuals across Sahelo- Saharan Africa. However, Stabach *et al*. (2017) dispute this figure, suggesting that it is "both out of date and likely to be inflated", although they do not offer an alternative estimate. In some areas, the situation is completely unknown.

The most recent full status estimate for the Dorcas gazelle on a country-by-country basis was published in 2007 and is summarised in Table 2.1 (UNEP/WCMC, 2007). The IUCN assessment published in 2017 contained no further, more recent, information. Further research is therefore required to understand its current status.

Table 2.1. Status of the Dorcas gazelle in the countries in its range in 2007

Country	Status reported as nationally threatened	Apparent trend
Algeria	•	↓
Burkina Faso	?	↓
Chad	•	↓
Djibouti	?	→
Egypt	•	↓
Eritrea	?	→
Ethiopia	?	→
Israel	?	→
Jordan	•	↓
Libya	•	↓
Mali	•	→
Mauritania	•	↓
Morocco	•	↓
Niger	?	→
Nigeria	ex	?
Senegal	•	↓
Somalia	?	→
Sudan	•	↓
Togo	?	?
Tunisia	•	?
Yemen	?	?

Key: ↑ = population increasing; → = population stable; ↓ = population decreasing; • = nationally threatened; ex = extinct; ? = no information or information uncertain (adapted from UNEP/WCMC, 2007)

Mallon and Kingswood (2001) estimated that there were between 2665 and 6515 Dorcas gazelle in protected areas in North Africa and the Middle East. This does not include more than 240 captive animals in Morocco, most of which were kept at Temara National Zoo and the Royal Farms of Bouznika. In 1999, there were up to 100 animals in captivity in North American and European zoos (East, 1999). In 2000, there was estimated to be more than 540 Dorcas gazelle in captivity worldwide (Mallon and Kingswood, 2001).

Mallon and Kingswood (2001) commented that, in many areas, further surveys were necessary to assess the population of Dorcas gazelle or to identify areas within its former range which are suitable for the release of animals bred in captivity. At that time a reintroduction programme was under consideration in pre-conflict Libya but has not happened to date. However, such programmes have happened in other countries within the range. Bro-Jorgensen and Mallon (2016) documented the best estimates of numbers of Dorcas gazelle reintroduced between 2007 and 2015 as follows: 524 in Tunisia, 1603 in Morocco and 63 in Senegal.

Chad and Niger were surveyed during the pilot phase of the Pan Sahara Wildlife Survey (PSWS) which operated from 2009 - 2012 (Wacher and Newby, 2012). Both countries border Libya to the south. The PSWS recorded Dorcas gazelles in all survey areas but found very low numbers in hunting zones and very low densities where livestock numbers were high. However, it highlighted very high populations of Dorcas gazelle in some areas, confirming the ability of the Dorcas gazelle to cohabit with humans who followed traditional, rural ways of life. Although it did not include Libya itself, the PSWS provided the most extensive and, in most cases, the first scientific estimates of the size and density of the Dorcas gazelle population in the region.

El-Alqamy and Baha El Din (2006) conducted a study of records relating to the status and distribution of Dorcas and Slender-horned gazelle in Egypt in the period 1997 – 2005. Detailed methodologies of the studies they referred to are not indicated and the sources include the personal observations and records of authors made during various field trips in each area. Based on these studies, El-Alqamy and Baha El Din (2006) claimed that the population size and range of both species had declined but at different rates. The Dorcas gazelle continued to exist in all of its known range in Egypt as well as in the area around the Siwa Oasis and in the west towards the border with Libya. El-Alqamy and Baha El Din (2006) reported that pilot surveys conducted by rangers in the Siwa Oasis area in 2004 showed concentrations of Dorcas gazelle, especially in the areas near the Libyan border. This suggested that it may extend into Libya, but further surveys were needed to confirm this. In some areas of the Egyptian desert, especially the western desert, such as Jabal Uweinat, there was insufficient data or no extant records and therefore they were unable to quantify the decline (see Fig. 2.4 for locations referred to above).

2.3.2. Status of the Dorcas gazelle in Libya

Misonne (1977 cited in Khattabi and Mallon, 2001) reported that the Dorcas gazelle was “quite common” in south eastern Libya in 1968-69 and estimated that, at that time, there were more than 100 in the Jabal Uweinat region (see Fig. 2.4). Essghaier (1980) reported that, in the 1960s, herds of up to 100 Dorcas gazelles existed on the Hamada El Hamra in western Libya. However, even by the mid-1970s, numbers had fallen, with only small groups being encountered. UNEP/CMS (1999) agreed that the Dorcas gazelle was still widely distributed across the northern and central regions of Libya in the 1960s and 1970s, although, according to Beudels *et al*. (2006), contemporaneous information on the distribution and numbers of the species did not exist.

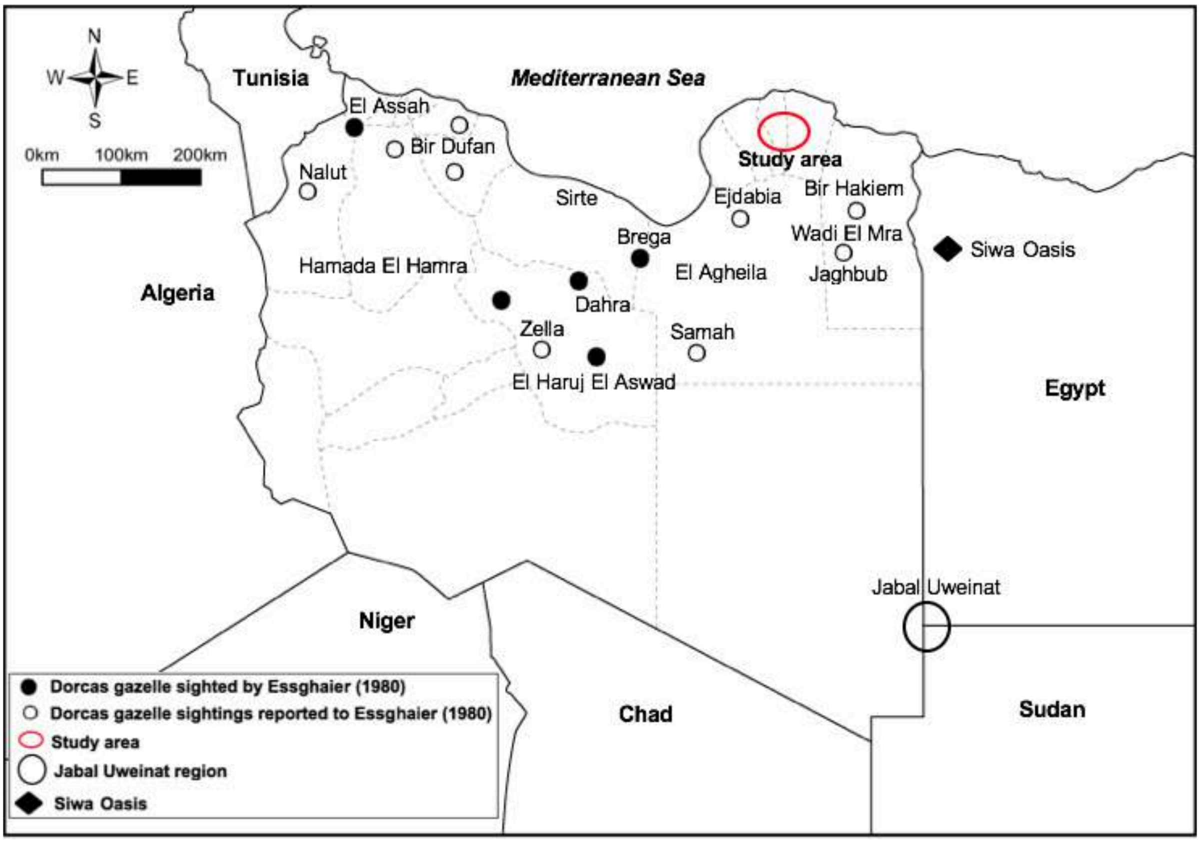


Fig. 2.4. Location of sightings of Dorcas gazelle reported in Misonne (1977 cited in Khattabi and Mallon, 2001), Essghaier (1980) and El-Alqamy and Baha El Din (2006) and their relationship with the area of the present study

Essghaier’s (1980) study contained an overview of the situation facing gazelle in Libya at that time (see Fig. 2.4). In the 1960s, herds in excess of 100 could be encountered in Gerardia and Nalut in western Libya. Khattabi and Mallon (2001) reported that, in the 1960s, herds of up to 100 animals were not uncommon, but by the early 1970s, it was unusual to encounter herds of 40. Essghaier (1980) also commented that by 1974, residents in these areas confirmed that the Dorcas gazelle population had decreased, especially those on the Hamada El Hamra, with only small herds being seen. Essghaier and Johnson (1981) reported that, from 1975 to 1976, there was a small population of about 35 Dorcas gazelles, protected by border patrols, near El Assah in the west. They were not detrimentally affected by the presence of livestock in the area. Essghaier and Johnson (1981) also reported a herd of 13 Dorcas gazelle at Dahra, and a group of 4 west of Dahra. On El Haruj El Aswad (the Black Hills), tracks and droppings were also frequently found in the wadis, and herds of one to three animals were occasionally encountered there.

Essghaier (1980) reported that in late 1974, about 40 gazelles (probably Dorcas) were seen near Samah, east of El-Haruj El Aswad. In February 1975, they received reports of a herd numbering about 30 near Brega. However, several of these had been killed by the later years of his study. In 1975, small groups of 3 to 8 Dorcas gazelle were reported by Essghaier (1980) in the region south of Sirte. According to East (1992), by the late 1980s, the Dorcas gazelle could still be found in certain parts of Libya, but its numbers were much lower. A similar situation of greatly reduced numbers was also reported by Khattabi and Mallon (2001).

In 2007, a study by the present author (Algadafi *et al*. 2017) into the status of the Dorcas gazelle in the area south of the Green Mountain and the neighbouring Libyan desert found that, whilst the species was still present, sightings had decreased considerably (by 60% - 90%) compared to historical estimates. The status of the Dorcas gazelle in Libya was characterised by a rapid and inexorable decline. Furthermore, by that time, it was the only antelope in the country and remains so (Algadafi *et al*. 2017).

2.4. Attitudes and threats to Dorcas gazelle

Khattabi and Mallon (2001) argued that the arrival of motor vehicles and the establishment of many oil-production facilities in the Libyan desert had contributed to the decline of wildlife in the desert. Essghaier *et al*. (2015) suggested that the reasons for the decline were that gazelle can easily fall victim to hunting from motor vehicles and habitat destruction. They note that gazelles were pursued by hunters in Jeeps until exhaustion killed them and this had been reported as early as 1972 by Hufnagl (1972).

The Sahara Conservation Fund (SCF) (2012) found that the ‘Arab Spring’ in 2011 had a significant impact on North African wildlife, including the widespread slaughter of wildlife. They reported that there were hundreds of photos on social media showing such slaughter, with the species most affected being the Dorcas and slender-horned gazelles and Barbary sheep. Much of the destruction of wildlife was thought to have occurred during the revolutions that deposed the former leaders of Tunisia and Libya, but there was significant evidence that poaching was continuing in Libya at that time (Plate 2.2 and 2.3), and in the deserts of southern Tunisia (Plate. 2.4 and 2.5) (SCF, 2012). Across the Sahara, motorbikes and quad bikes were being used as weapons. Wacher and Newby (2012) found evidence of a desert hunting trade involving the slaughter of Dorcas gazelle in the Sahara. Motorcycles and pick-up trucks were used to transport the carcasses, probably to be sold in towns and countries further south.

Plate 2.2. Photos revealing the slaughter of Dorcas gazelle (left) and the presence of Arabian sand gazelles (right) imported into Libya (SCF, 2012)

Plate 2.3. Hunting activities from vehicles in Libya (SCF, 2012)

Plate 2.4. Slender-horned gazelles killed in southern Tunisia (SCF, 2012)

Plate 2.5. Motorbike and quad bikes which are capable of chasing down and exhausting wildlife over difficult terrain (SCF, 2012)

2.5. Social factors in conservation: the role of questionnaires

White *et al*. (2005) stated that questionnaires are a useful tool in ecological research when information is required from a specific human population in order to test hypotheses. According to Newing *et al*. (2011, p.145), “questionnaires are precise and powerful tools for collecting an enormous amount of carefully-focused information from a large number of people”. White *et al*. (2005) argue that, in the domain of ecology, questionnaires are especially valuable for investigating the views of the public or other stakeholders concerning issues such as measures to manage the ecology, and for large-scale research projects and studies to evaluate the impact of the human population on wildlife. In such studies, questionnaires are often the best way to collect quantitative data from a large number of locations. Field surveys are useful to understand the present impact of human activity or specific management initiatives, but they do not usually provide information about the impact of such matters in the past. Consequently, questionnaires are a particularly useful research tool (White *et al*. 2005). Furthermore, if researchers wish to combine ecological and socio-economic or political data, questionnaires can play a valuable role (White *et al*. 2005).

Bernard (2011) stated that there are four main ways in which data can be gathered: (a) personal interviews (face-to-face with the interviewer), (b) self-administered questionnaire where the interviewer is no present, (c) telephone interviews and (d) online surveys.

Suárez *et al*. (2012) point out the importance of selecting key informants with care to ensure that a conservation project proceeds successfully. Bernard (2006) defines key informants as: members of a community or institution who are knowledgeable about the topic of interest, usually through experience, and these individuals are willing to share their experiences and expertise. They should also understand different practices within the whole community as well as their own, individual practices (Crandall *et al*. 2018). Anderson (2005 p. 56) suggested that such informants should also have “traditional knowledge or traditional ecological knowledge”.

Key informants who agree with or disapprove of specific conservation goals or programmes can help to bring together differing opinions (Crandall *et al*. 2018). This is especially the case if both researchers and local residents show equal respect for local values and culture. The local knowledge of key informants can be used to map the location of a target species and to understand its abundance and distribution. Crandall *et al*. (2018) argued that the results from such studies can be used to assist with the creation of protected areas and they help to gain a clearer understanding of the practices and needs of local stakeholders which can lead to better outcomes for environmental management.

An example of an ecological research study that used questionnaires is that by Sillero-Zubiri *et al*. (2013) in east Niger. They conducted an attitudes survey to explore the attitudes and perceptions of local people towards carnivores and human-wildlife conflict. Two questionnaires were used, with most questions requiring responses on a 5-point Likert scale while others were open ended. Another example is a study by Karris *et al*. (2013), where a questionnaire with closed and open-ended questions was used with local stakeholders to assess whether seabirds pose a threat to bird populations in a region of the Mediterranean. A study conducted by Dutton *et al*. (2015), used a questionnaire to explore the social aspects of wild boar occupation and interactions with people in the Forest of Dean, England.

2.6. Methods for estimating ungulate abundance and density

Knowledge of population size and population structure is essential for the development of effective management strategies for ungulate populations (Marques *et al*. 2001). However, no method of population assessment has yet been developed which allows the exact number of animals in an area to be determined (Acevedo *et al*. 2010). Sutherland (1996; 2006) has reviewed many of the methods used to survey mammals, and reported that line transects, aerial line transects, and dung counts are the most frequently used. El-Alqamy (2003) argued that total counts and individual recognition are "often applicable" methods and capture-recapture and use of feeding signs are "sometimes applicable". Additionally, Wronski *et al*. (2013) state that latrine mapping may also be an effective, time- and cost-efficient, non-invasive tool to use in remote areas with low population densities.

Methods to estimate population abundance are broadly classified as direct or indirect and all are subject to bias and uncertainty. The most valuable are those for which levels of uncertainty can be quantified and are relatively low. Confidence can be increased where different techniques yield similar results (Marques *et al*. 2001).

Marques *et al*. (2001) suggested that direct methods, such as observation of individual animals, can enable the estimation of the number and sex of the target species whereas indirect methods, such as observation of tracks or dung, only give an estimate of its overall abundance. A further difference between direct and indirect methods is that the latter usually facilitate estimates of average abundance over a longer period, whilst the former usually only give estimates of abundance on the day the survey is carried out, which may be misleading.

2.6.1. Direct methods

Direct methods are based on surveys, or counts, of the animals (Focardi *et al*. 2002; Ward *et al*. 2004) and generally enable an estimation of their population structure in addition to abundance (Acevedo *et al*. 2010). One widely-used direct method is to conduct a complete census, either on the ground or from the air (examples include Caughley, 1980 and El-Alqamy, 2003). Both ground and aerial censuses have proved helpful for targeting small, confined populations, but are less effective for widely-spread, small groups of individuals (Noyes *et al*. 2000; El-Alqamy, 2003). Stabach *et al*. (2017) have suggested that perhaps the best way to count and monitor a species which inhabits large open areas, such as the Dorcas gazelle, is a combination of ground and aerial surveys. However, as both Lamprey (1964) and Goddard (1967) have pointed out, a particular drawback of aerial surveys is that individual animals may go unnoticed.

Seber (1982) has suggested that a better approach to count the number of animals and calculate the density of the species in a study area is to use transects. According to Marques (2009, p. 136), transects are “sampling units which cover a proportion of the survey region over which the population of interest exists”. However, according to El-Alqamy (2003), the animals counted in an area are not complete in most circumstances, and the percentage of the total population the count represents is unknown. Consequently, it is important to correct for sampling observation probability (for example, detectability). The probability of detecting an animal within the survey area must be known in order to estimate population abundance or density.

There are a number of different types of transect, including strip or belt transects, and line transects. El-Alqamy (2003, p. 16) defines a strip transect as “a modified plot count where the plot is elongated rather than square”. The strip transect approach is most frequently used in aerial surveys, because the time available is too short to estimate the distance of each animal from a transect line. An example of a study adopting this approach is Marques and Buckland’s (2003) survey of red deer in Scotland. Studies of this type have increased the levels of confidence and detectability and are a valuable refinement of survey-based models. Detectability can be improved further through the use of a narrow strip transect but according to Marques *et al*. (2001), a more efficient method that is less susceptible to bias is the line transect advocated by Buckland *et al*. (1993).

A line transect involves establishing a transect line along a specific gradient. In ‘continuous sampling’, the species that are encountered along the full length of the line are recorded, whereas in ‘systematic sampling’, presence or absence is recorded at marked points along the line (Buckland *et al*. 1993). Although only a small section of a much larger area is sampled using this method, it enables an accurate representation of flora and fauna to be identified. A study which used a line transect method to estimate the abundance of sika deer (*Cervus nippon*) from dung in southern Scotland was that of Marques *et al*. (2001). However, precision was poor, especially in areas with small sample sizes.

El-Alqamy and Harwood (2003) have indicated that line transects need to be used over long periods of time if incremental population changes are to be detected for Dorcas gazelle because the accuracy of the results increases with a greater number of annual surveys.

2.6.2. Indirect methods

Indirect surveys are a well-established method to estimate population size (Jachmann, 1991; El-Alqamy *et al*. 2001; Swanson *et al*. 2008; Thomas *et al*. 2010; Gil-Sanchez *et al.* 2017). They enable 'indices' of population density and abundance to be identified, from which the relation between indices and population estimates can be established (El-Alqamy, 2003). According to Putman (1984), indirect methods only give an estimate of the overall population abundance.

Such methods were used by Marques *et al*. (2001) to estimate the abundance of deer populations and it has also been used with wild guinea pigs (Cassini and Galante, 1992), elephants (Barnes *et al*. 1995) and a number of other large vertebrates (Hill *et al*. 1997).

A particularly pertinent indirect method is to assess the amount of dung in a given area (Marques *et al*. 2001; Smart *et al*. 2004). The presence of a species in an area can be ascertained by dung counts and the DNA in fresh dung can also potentially become a way of estimating population size through the analysis of dung from specific individuals (Eggert *et al*. 2003). Sutherland (2006) has suggested that if the dung produced by a species is characteristic, it is often simpler to find and count rather than attempting to capture the actual animals. Presence of dung is usually used as an indicator of the presence of a species, but some studies have tried to use the volume of dung to assess the abundance of a population. However, Sutherland (2006) warns that biases can occur because the distribution of dung is not usually random, and it decays at variable rates according to environmental conditions, so caution is needed. Furthermore, the issue of establishing the age of dung can be problematic due to the destruction and decomposition of pellets or other factors.

Marques *et al*. (2001) state that any attempt to assess the quantity of dung relys on an understanding of other factors such as defecation rates which typically vary with the season, age and diet. El-Alqamy (2003) suggests that, ideally, defecation rates should be estimated from direct observation of wild animals as values from zoo animals are often unreliable. However, he acknowledges that this is often impractical and that it may be better to estimate defecation rates from semi-captive animals, provided they are kept in natural habitats and receive little supplementary food. Krebs *et al*. (2001) suggest that an alternative approach is to integrate dung counts with estimates of the size of the population in the area. This can enable the relationship between dung counts and population size to be estimated empirically (Sutherland, 2006).

The dung of several species takes the form of faecal pellets often found in groups. Several indirect methods to count faecal pellets or pellet groups have been used in order to estimate the abundance of ungulate populations, including (i) the number, or frequency, of pellet groups on transects (Acevedo *et al*. 2007), (ii) counts of pellet groups in plots (Smart *et al*. 2004) and (iii) the application of distance sampling on line transects to estimate faecal density (Marques *et al*. 2001). Only the last two of these can be used to obtain pellet group densities and, eventually, estimate population densities provided the defecation rate and length of time to dung decay is known (Acevedo *et al*. 2010).

Marques *et al*. (2001) warned that estimating both dung decay rates and defecation rates can be problematic as there are many possible sources of bias. They argue that the suitability of the method used will vary according to the ecology and behaviour of the target species, the management issues involved, the type of habitat, season and substrate.

A further useful indirect method for detecting the presence of a species is to search for footprints in areas of soft ground which can give a “crude but quick indication of abundance” (El-Alqamy, 2003, p. 13). An example of a study that used this method is Mooty and Karns (1984). One drawback of this method is that it is difficult to be certain how many individuals produced the sets of prints. Another, as identified by Sutherland (1996), is that differences in behaviour according to the season and habitat may lead to bias in the estimates of density or abundance.

Another indirect method is to conduct a latrine site (the location where groups of pellets are found) survey. This was used by Wronski and Plath (2010) and Wronski *et al*. (2013) to estimate the population of Arabian gazelle (*Gazella arabica*) in Saudi Arabia. They found that the density of latrine sites was a good indicator of home range in female groups. A logarithmic model was used to confirm the expected non-linear relationship between gazelle numbers and the number of latrines.

In areas of extensive open ground, both direct and indirect count methods can be used, although the former are generally more effective and are more widely used (Acevedo *et al*. 2010). In the present study, both types of method were used but the emphasis was on indirect methods.

2.6.3. Distance Sampling methods

A number of studies have attempted to estimate the abundance and density of ungulate populations in different regions of the world using distance sampling methods. According to Buckland *et al*. (1993) distance sampling is not a single method but rather a collection of closely-related methods where the main approaches involve line transects and point transects. Both involve performing a systematic survey along a series of lines or points in order to identify items of interest, usually individuals or groups of animals. The distance of the object from the line or point is recorded. Acevedo *et al*. (2010) argue that distance sampling is useful in estimating the density of groups of faecal pellets. Using this approach, Buckland *et al*. (2001) demonstrated that the number of pellet groups can be modelled based on the perpendicular distances of detected pellet groups from the transect line.

All distance sampling methods rely on the use of a ‘detection function’. This is a model which calculates the probability of detecting a specific organism, such as an individual animal or dung, in relation to its distance from a transect (Buckland *et al*. 2001 and Thomas *et al*. 2010).

Wacher and Newby (2010) used distance sampling to count numbers of individual Dorcas gazelle in the Manga and Eguey regions of Chad. They reported the densest population of Dorcas gazelle ever recorded in that country. Their study confirmed that detection probabilities for Dorcas gazelle diminished rapidly beyond 150 m from the observer (Fig. 2.5).

Elsewhere, Acevedo *et al*. (2010) used distance sampling as a method for estimating the abundance of roe deer (*Capreolus capreolus*) in Mediterranean woodlands in Spain based on pellet group counts. El-Alqamy *et al*. (2011) also used distance sampling surveys of gazelle droppings along line transects to study the decline of Dorcas gazelle in South Sinai, Egypt, during the period 2006 to 2011. Figure 2.6 shows the detection function used in their study.

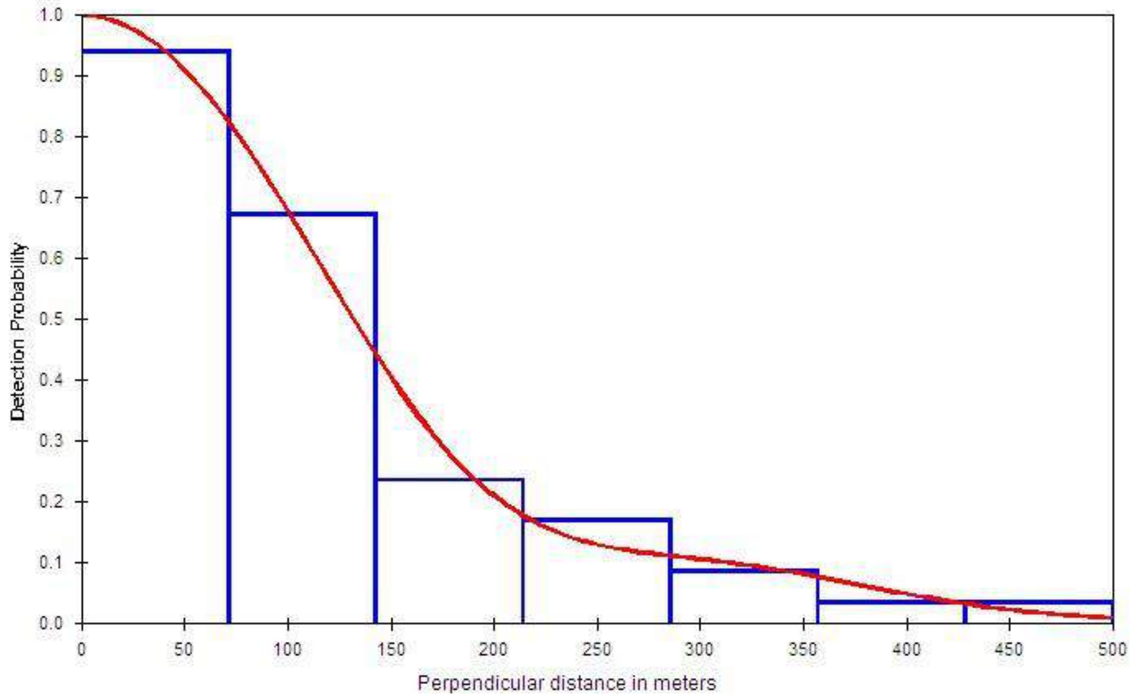


Fig. 2.5. Detection probabilities for individual Dorcas gazelle with distance from vehicle on transect (Wacher and Newby, 2010)

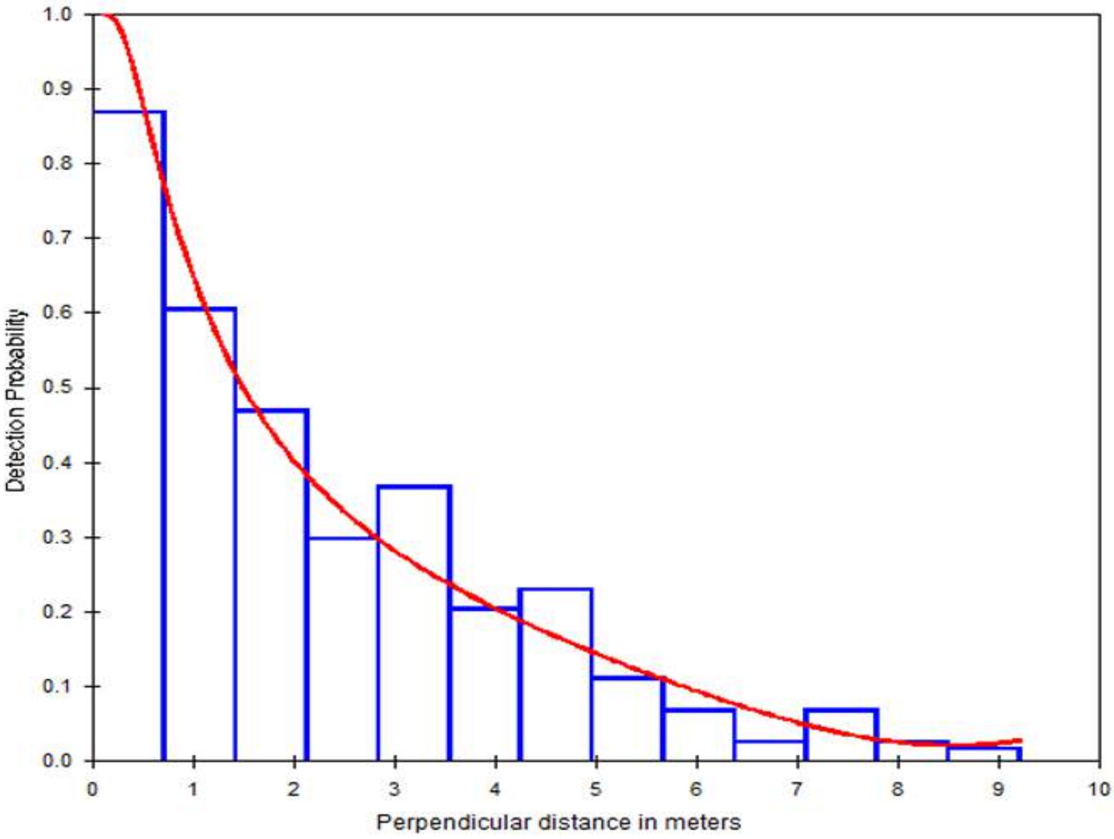


Fig. 2.6. Detection function for Dorcas gazelle droppings using pooled detections from all years (El Alqamy *et al*. 2011)

Faecal pellet group surveys using distance sampling have been shown to be a helpful methodology for estimating abundance and density of ungulates. However, low animal numbers may impose considerable limitations on the possibility of estimating defecation rates in natural or semi-natural conditions. Line transects allow coverage of large areas and enable precision of estimates provided the models used for data analysis are robust.

2.6.4. Survey design

Whether direct or indirect methods are used, good survey design is essential in order to obtain reliable results. The principles of replication and randomisation must be included. Buckland *et al*. (1993) reviewed survey design in the context of line transect sampling and concluded that it is important to make sure that there is equal coverage across the area to reduce the risk of any bias. Marques *et al*. (2001) considered design in the context of deer surveys. The transects need to be placed within the study area to account for the differing densities of populations. Pilot surveys are useful in situations where little is known about expected population densities (Marques *et al*. 2001).

Fewster *et al*. (2009) and Thomas *et al*. (2010) also emphasised the need for systematic survey design and further discussion of design issues can be found in Buckland *et al*. (2001, 2004), Strindberg *et al*. (2004), Williams and Thomas (2010).

2.7. Genetics and conservation biology studies

According to Wronski *et al*. (2010), the taxonomically-correct identification of populations of endangered species is essential for the success of conservation programmes. Taxonomically, the most complex group within the Bovidae is the Antilopinae (the true antelopes) (Groves, 1981). Morphological characteristics such as body size, horn shape, and pelage coloration have been primarily used to describe different taxa. However, mitochondrial DNA (mtDNA) variation has also been widely used in the description of taxa which are difficult to distinguish morphologically. Many studies have utilised mtDNA sequence variation for the quantification of genetic variation and to resolve problems in the classification or conservation of gazelle species (Hammond *et al*. 2001; Rebholz and Harley, 1999; Wronski *et al*. 2010; Wacher *et al*. 2011).

A number of studies have used genetic analysis to attempt to identify subspecies within the Dorcas gazelle genus, their origins and genetic diversity. Lerp *et al*. (2011) attempted to identify a phylogeographic framework for the conservation of

Saharan and Arabian Dorcas gazelle. Their study included samples from *G. dorcas* and *G. saudiya* from across the full range of their distribution. Their samples came from the Sahara in West Africa as far as Saudi Arabia (see Fig. 1.1 on p. 4). Their analyses shed doubt on the validity of various previously-described subspecies of Dorcas gazelle.

Lerp *et al*. (2011, p. 325) argued that, contrary to certain other gazelle taxa, Dorcas gazelles form one “evolutionarily significant unit” (ESU). They suggested that the few genetic differences between the different groups of Dorcas gazelles, from as far apart as Mali and the Sinai, indicate that the continuing gene flow is high as a result of migration or a recent expansion in range. They also claimed that “morphological differences are sometimes poor indicators of species boundaries or genetic differentiation among populations” (Lerp *et al*. 2011, p. 325). To support this claim, they cited a phylogenetic study by Wronski *et al*. (2010) into the divergence of mitochondrial cytochrome b sequences in mountain gazelle (*Gazella gazella*), a species closely related to Dorcas gazelle. Wronski *et al.’s* (2010) study demonstrated that there are two genetically-distict lineages. One of them occurs only in a small area in the Golan Heights and can be regarded as a separate species. Lerp *et al.*’s (2011) findings are given support by Habibi (2011), who proposed a classification based on strict adherence to the concept of a ‘Phylogenetic Species’.

Hammond *et al*. (2001) undertook a phylogenetic re-analysis of the Saudi gazelle in order to explore the implications for its conservation. They used 375 base pairs of mtDNA cytochrome b gene. The samples were collected from specimens in museums which had been obtained before the species was thought to have become extinct. They found that *Gazella saudiya* is the “sister taxon” of Dorcas gazelle, and that the reciprocal monophyletic closeness of *G. saudiya* mtDNA haplotypes to those of the Dorcas gazelle, suggests a close relationship between them, with only small genetic distances. This may indicate that they form an ESU (Lerp *et al*. 2011). All of their samples had mtDNA haplotypes which are consistent with the origin of the matriline from African Dorcas gazelle, rather than the Arabian *G. saudiya*. They also found low nucleotide differences between the haplotypes of *G. saudiya* and Dorcas gazelle, indicating close genetic similarity.

Lerp *et al*. (2011) pointed out that the study by Hammond *et al*. (2001) supersedes that of Rebholz *et al*. (1991), who believed that the Saudi gazelle was only distantly related to the Dorcas gazelle. Lerp *et al.'*s (2011) own study finds that the Saudi gazelle is definitely in the same clade as the Dorcas gazelle, with only small genetic distances from other species in this clade.

Lerp *et al*. (2011) however disagree with Gentry's (1964) claim that the Dorcas gazelle's origin is Palearctic and from there extended into North Africa. Their study found the largest diversity of haplotypes in the south-central and south-eastern parts of its present range and therefore they believe that this is the most probable centre of the species' origin (Fig. 2.7). Furthermore, Lerp *et al*. (2011) found no differences between their samples from the south-central and south-eastern areas. They suggested that the species may have spread from here to other places where it is currently found, including the Arabian Peninsula. They also found a weak gene flow between specimens from the Sinai and the Arava valley (the locations are identified in Fig. 2.2 on p. 17, points 20 and 21 respectively) and conclude that this indicates the presence of a geographical barrier between the groups which prevents migration. They argue that the most likely barriers are the Red Sea and the Nile delta. In order to test this idea, they suggested that Dorcas gazelles from Libya and Egypt should be studied further (Lerp *et al*. 2011) and this contributes to the justification of the present study.

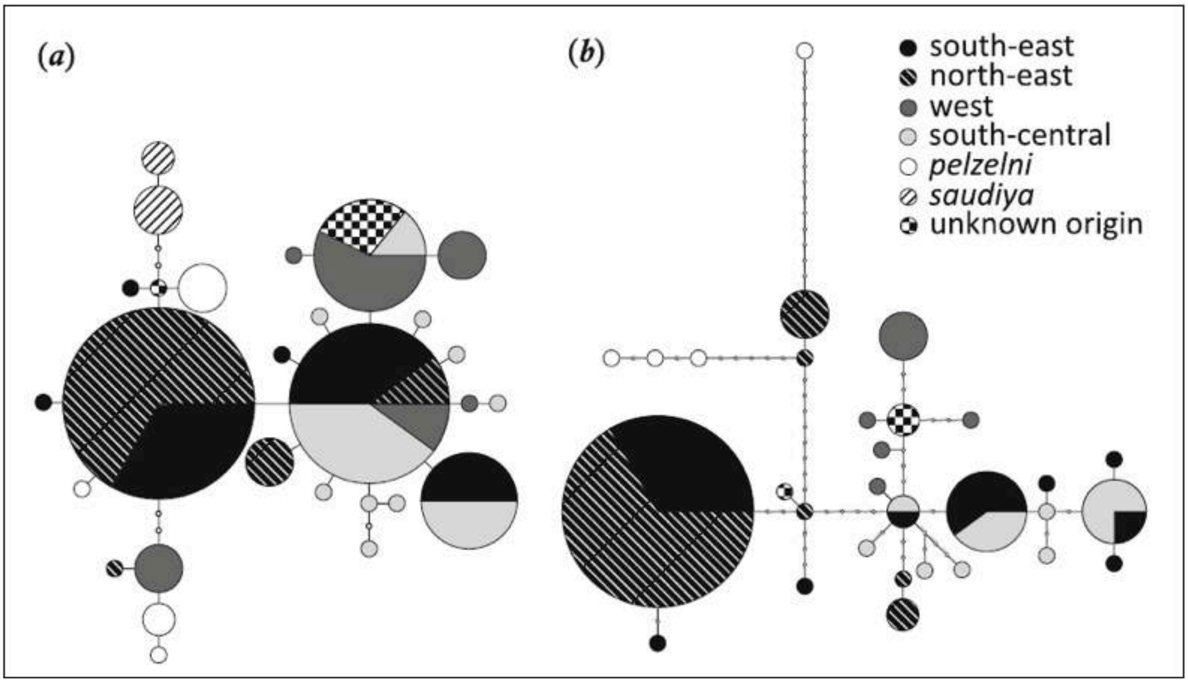


Fig. 2.7 a and b. Statistical parsimony network based on (a) a 412 bp fragment (73 sequences) and (b) the complete cytochrome b gene (57 sequences). Each circle represents a different haplotype, whereby circle size is proportional to the number of individuals in the data set with that haplotype (legend size represents one animal). The colour code indicates the origin of the samples (see legend). Smaller open circles represent missing haplotypes, and connecting lines correspond to one mutational step (from Lerp *et al*. 2011, p. 324)

Lerp *et al*. (2011) cited studies by a number of scholars to indicate that paleogeographic data suggests that the Dorcas gazelle may have spread from drier areas into the Mediterranean region during the post-Neolithic period to replace *G. gazella*, which prefers a more humid environment. Their findings suggest a close relationship between Dorcas gazelle from Sinai and the Levant and Pelzeln's gazelle (*Gazella dorcas pelzelni*) (Fig. 2.7b), which indicates that, in the more humid period after the last glacial period approximately 22,000 years ago, there may have been an unbroken population from Israel to Somalia, east of the River Nile.

Godinho *et al*. (2012) conducted a study on the conservation genetics of the endangered Dorcas gazelle in Morocco in northwest Africa. They found low levels of genetic diversity in their wild, semi-captive and captive populations. Also, the genetic structure of their Dorcas gazelle populations showed distinctive taxonomic features compared with the subspecies proposed by certain researchers. They concluded that semi-captive and captive populations are significant for the conservation of Dorcas gazelle in North Africa.

A recent study by Hadas *et al*. (2015) used genetic profiling to identify new conservation priorities for wild gazelles of the southern Levant. Three regions of mitochondrial DNA (control region, cytochrome b and 12S ribosomal RNA) and nine nuclear microsatellite markers were used to identify the genetic make-up of 111 wild gazelles from Israel. Their results showed that there is sufficient diversity and gene flow between subpopulations. The Dorcas gazelles in Israel showed generally wide genetic diversity despite inbreeding within subpopulations. The authors proposed a different hypothesis from Lerp *et al*. (2011) and Godinho *et al*. (2012) for the historical spread of the Dorcas gazelle. Hadas *et al*. (2015) believed that the species had spread to northern Africa from the southern Levant. Bayesian phylogeny and the CR haplotype network led them to identify four majors '*clusters*': mountain gazelle, Dorcas gazelle and two '*clusters*' of Arabian gazelle. The mountain gazelle in the samples showed close relationships and were distinct from the other populations. This suggests an element of uniqueness and low genetic diversity (Fig. 2.8). As had been hypothesised, the Dorcas gazelle from Israel were closely related to the African Dorcas gazelles, despite the lack of any shared haplotypes (Fig. 2.8).

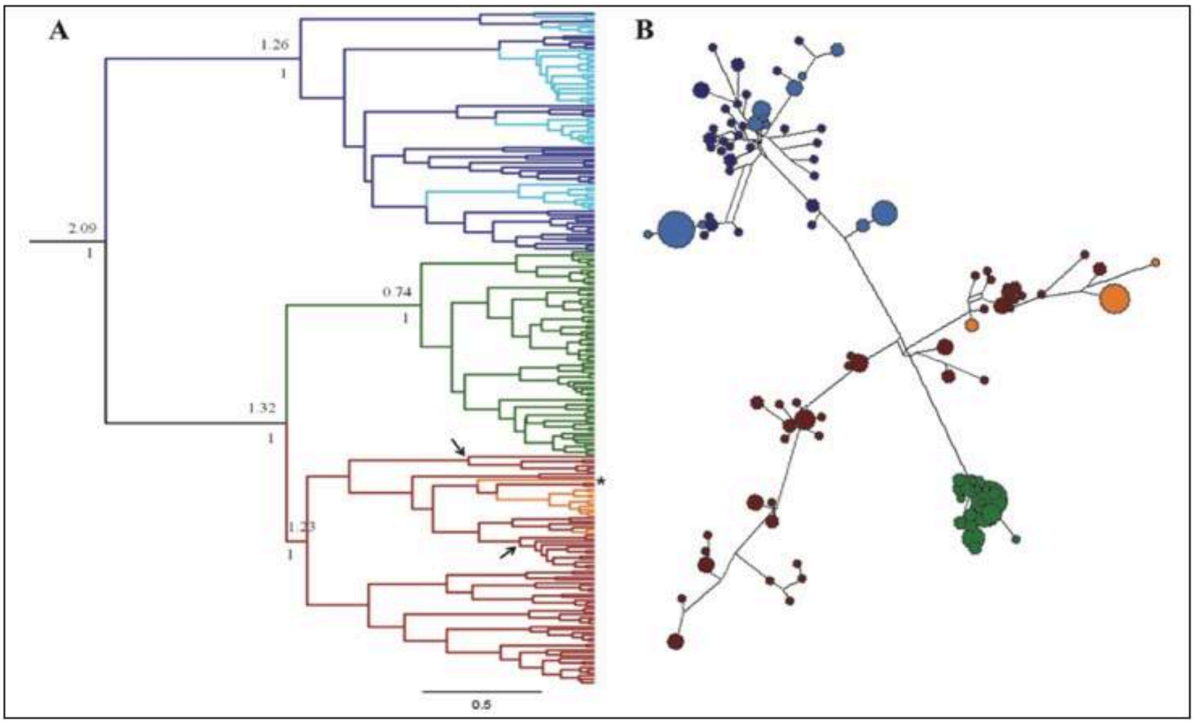


Fig 2.8. Genetic relationship among gazelles from the Southern Levant and other localities. A. Bayesian phylogenetic reconstruction. The phylogenetic analysis is based on sequences obtained from 230 individuals, 200bp of the control region, representing populations from the Southern Levant and from neighbouring localities (after, Lerp *et al*. 2011). Numbers above the nodes represent node age in MYA while numbers below the nodes represent the posterior probability. Mountain gazelles are represented by the green colour; Dorcas gazelles from Israel are represented by the light blue colour; Dorcas gazelles from northern Africa are represented by the darker blue colour; acacia gazelles are represented by the orange colour and Arabian gazelles are represented by the red colour. Dorcas gazelle 13 is marked with an asterisk. Clades of the Arabian gazelles from the Farasan Islands are marked with an arrow at the node. B. Median-joining haplotype network. Size of the circle is proportional to the frequency of the haplotype. The colours are the same in the phylogenetic tree (from Hadas *et al.* 2015)

Hadas *et al*. (2015) found a high level of variation within the Israeli Dorcas gazelle population, including haplotype diversity (Hd) and nucleotide diversity (π) values. This level of diversity was even higher than that found by other researchers, such as Godinho *et al*. (2012), who had also found considerable levels of genetic diversity and a relatively stable population size. Godinho *et al*. (2012) had concluded that the Morocco population of Dorcas gazelles was an important source of genetic variability which may be significant for future conservation activities throughout its range. Hadas *et al.*'s (2015) genetic analysis also found a geographic separation of haplotypes (Fig. 2.9). The closest genetic relation to the Israeli Dorcas gazelle population was found in the specimens from Sudan (Fig. 2.8).

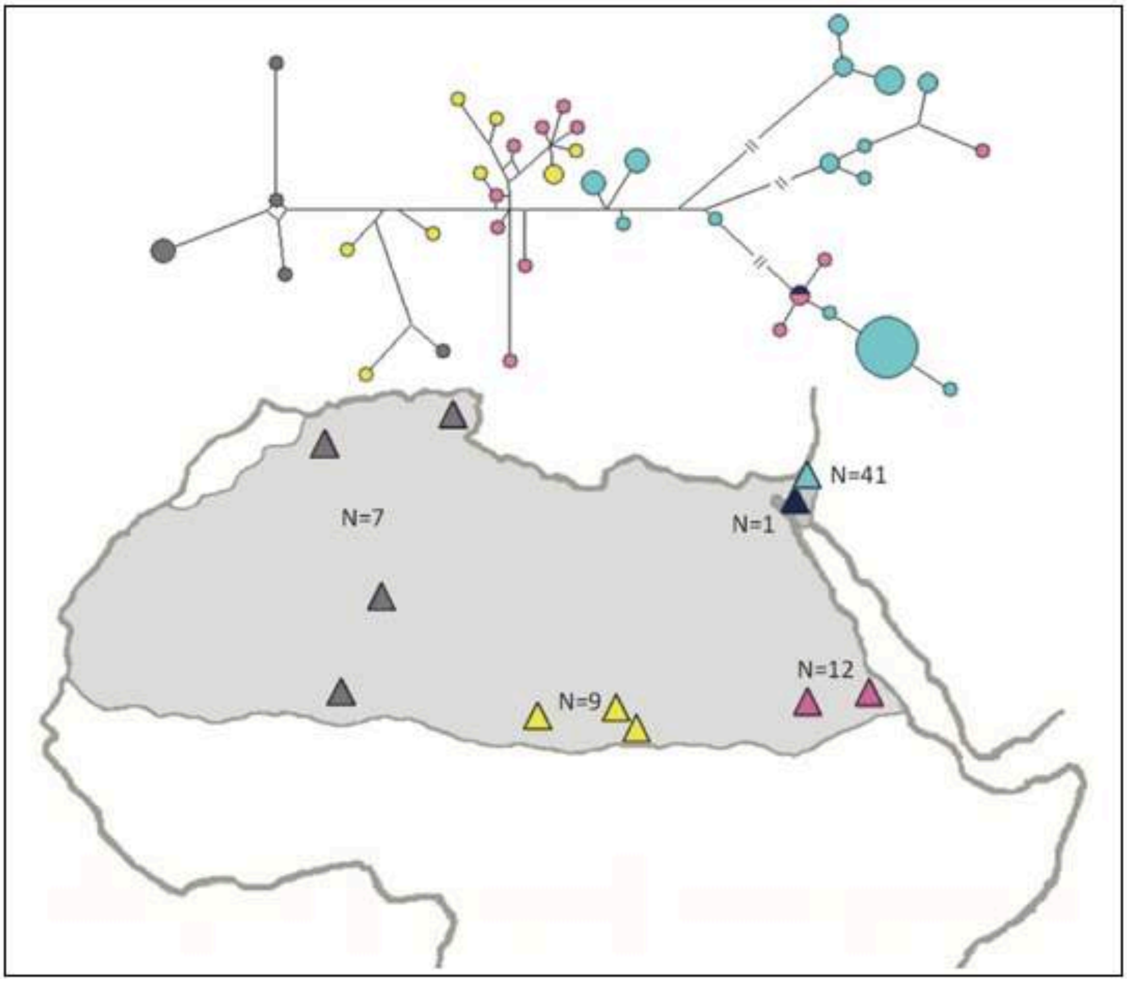


Fig 2.9. Median-joining haplotype network showing the relationships among Dorcas gazelle populations across the species range. Range of Dorcas gazelle distribution is shown on map in light grey, based on IUCN and published literature (Lerp *et al*. 2011; Durant *et al*. 2014). Triangles represent sampling locations, colours represent geographic grouping of samples (after, Lerp *et al*. 2011): Dark grey represents west, yellow represents south-central, pink represents south-east, dark blue represents Sinai and light blue represents Israel (data). Haplotype network is based on concatenation of a 607bp fragment of CytB and a 200bp fragment of the CR, for a total of 70 individuals. Size of the circles is proportional to the frequency of the haplotype and the circle colours match geographic groupings (from Hadas *et al*. 2015)

Senn *et al*. (2014) used mtDNA control region and cytochrome b data to study the genetic relatedness and diversity in three wild dama gazelle (*Nanger dama*) populations from the five that still exist in Niger and Chad and certain populations in captivity. They came from three previously identified subspecies. Cytochrome b haplotype groupings were overlaid on the control region network. They concluded that the genetic data did not support the division into sub-species and therefore, for conservation purposes, the dama gazelle should be regarded as a single species without subdivisions.

The present study uses a similar methodology to those discussed above, but limited to mtDNA cytochrome b analysis, to identify the haplotypes of Dorcas gazelle in the study area.

2.8. Conservation action

A number of scholars have reported notable successes for traditional conservation approaches, including habitat restoration, the removal of anthropogenic pressures and invasive species, and establishing networks of protected areas (Rands *et al*. 2010; Stork, 2010; Dawson *et al*. 2011). Lee and Jetz (2008) and Rands *et al*. (2010) argued that protected areas are vital for the conservation of ecosystems and biodiversity. However, others such as Gordon (1991), Bruner *et al*. (2001) and Venter *et al*. (2008) suggested that they do not guarantee the protection of all species living within them. This led Shaffer (1981) to call for a more species-driven approach to conservation. Aulagnier *et al*. (2001) also suggested that to reverse declines in populations, effective protection is required from poaching, habitat loss and predation by feral dogs.

According to Höglund (2009) and Wilson *et al*. (2004), populations of endangered species are often on the decline and becoming fragmented. It is therefore important that targeted action includes reducing threats such as overhunting as well as the protection of habitats, intensive captive management and reintroductions (Pullin, 2002; Caro, 2003; Rands *et al*. 2010). It is generally considered that the conservation of a species is most effective when it occurs within the species' natural habitat (Caro, 2003; Redford *et al*. 2011). This approach has the benefit that it also preserves other species and their interactions with each other and the environment. In other words, the focal species becomes an umbrella for wider conservation (Balmford *et al*. 1996; Pullin, 2002; Redford *et al*. 2011). The survival of many species now depends on conservation and long-term action (IUCN, 2017).

2.8.1. Protection legislation (in Libya)

According to Essghaier (1980), a wildlife protection law was passed in 1955 in Libya and reinforced in 1965. It prohibited hunting from 1970 – 1975. In 1975, a temporary ban was introduced on the sale of weapons and ammunition to assist the conservation efforts for endangered species. Theoretically, therefore, Libya's laws on hunting were exemplary:

> it is not permitted to kill female gazelle; the capture, removal and sale of young wild gazelle is prohibited; a licence is required for hunting and the permitted hunting season for gazelle lasts only for a few weeks starting in mid-August. Hunting is not allowed from vehicles or aircraft and the trade in gazelle meat (venison) is prohibited (Khattabi and Mallon, 2001 p. 42).

However, Essghaier (1980) reported that these actions were not enough to prevent hunting and Hufnagl (1972) stated that the laws were not adequately enforced and there was a lack of awareness about them on the part of many hunters. Attempts in 1982 to improve the wildlife protection laws also failed (Khattabi and Mallon, 2001). However, they did result in the issue of hunting licences and permits and the introduction of tighter regulations. Khattabi and Mallon (2001) argued that this led to more game species being observed in several parts of Libya. Better enforcement of the legislation in the 1990s also contributed to some improvement in the situation. However, enforcement has become more complicated since the war in 2011. The conflict in Libya is ongoing and extremely high numbers of animals have been killed (SCF, 2012; Brito *et al*. 2018).

2.8.2. *Ex situ* and *in situ* captive breeding and reintroductions

According to Gilbert (2011), the continuing crisis in biodiversity requires the intensive management of an increasing number of species in captivity if they are to avoid extinction. The IUCN (2017) recommended that taxa of scientific or cultural importance that are facing threats, and all taxa classified as 'Critically Endangered' and 'Extinct in the Wild', require intensive *ex situ* management.

Ex situ captive breeding involves moving some (or all) of the remaining population from the wild into captivity to instigate breeding and to ultimately protect the species from global extinction. According to Olds (2014), such programmes can be an extremely valuable tool in protecting species as they allow a population, both worldwide and limited to certain areas, to be manipulated genetically and demographicaly. This can facilitate improvements in genetic diversity (Maunder and Byers, 2005). Pritchard *et al*. (2012) argued that captive animals can be used to increase wild populations.

In situ captive breeding, according to Pritchard *et al*. (2012, p. 21) involves "the manipulation of the reproductive potential of wild pairs" and includes propagation and reintroduction or supplementation. Owen *et al*. (2014) reported that the persistence of a population should be supported with approaches such as supplementary feeding. However, Olds (2014) warned that an *in situ* captive programme requires an understanding of whether such a programme would be helpful for a specific species, skills in the use of the required tools and techniques, and an evaluation of its practicality, including consideration of existing pressures on the habitat.

According to Newby *et al*. (2016), captive breeding programmes that are well-coordinated, especially those in the USA, Europe, and the Middle East, can help to sustain populations of Sahelo-Saharan ungulates that are at risk and to guard against the extinction of certain species. Such programmes are being used more and more in reintroduction projects in North Africa (Bro-Jorgensen and Mallon, 2016).

However, Bro-Jorgensen and Mallon (2016) go on to argue that there are also challenges for captive populations as a result of the frequently small founding populations and poor documentation. There is also the risk that they will not adapt adequately to captivity, and that the population is not large enough to retain genetic diversity in the long-term. Ballou *et al*. (2010) argued that, at that time, zoo populations in the USA and Europe were very small and isolated, resulting in an increased extinction risk from demographic stochasticity.

Another approach used in conservation is translocation. The IUCN (2013, p. 1) defines translocation as ‘the human-mediated movement of living organisms from one area, with release in another’. Hayek *et al*. (2016) recommended that any programme designed to use translocation as part of a conservation strategy, such as wild-to-captive breeding and release, or wild-to-wild translocation, should use, or at the very least, refer to, the IUCN’s (2013) translocation guidelines. These guidelines identify a number of stages to be followed in the design, implementation and follow-up of any translocation programme (Fig. 2.10). These include an analysis of the current conservation status of the target species, identifing the goal and evaluating possible alternative courses of action. This includes completing a risk assessment and conducting a feasibility assessment (IUCN, 2013).

Translocations should be fully documented, and their outcomes made publicly available to inform future conservation planning. Well-planned and efficient post-release monitoring is particularly important (IUCN, 2013.).

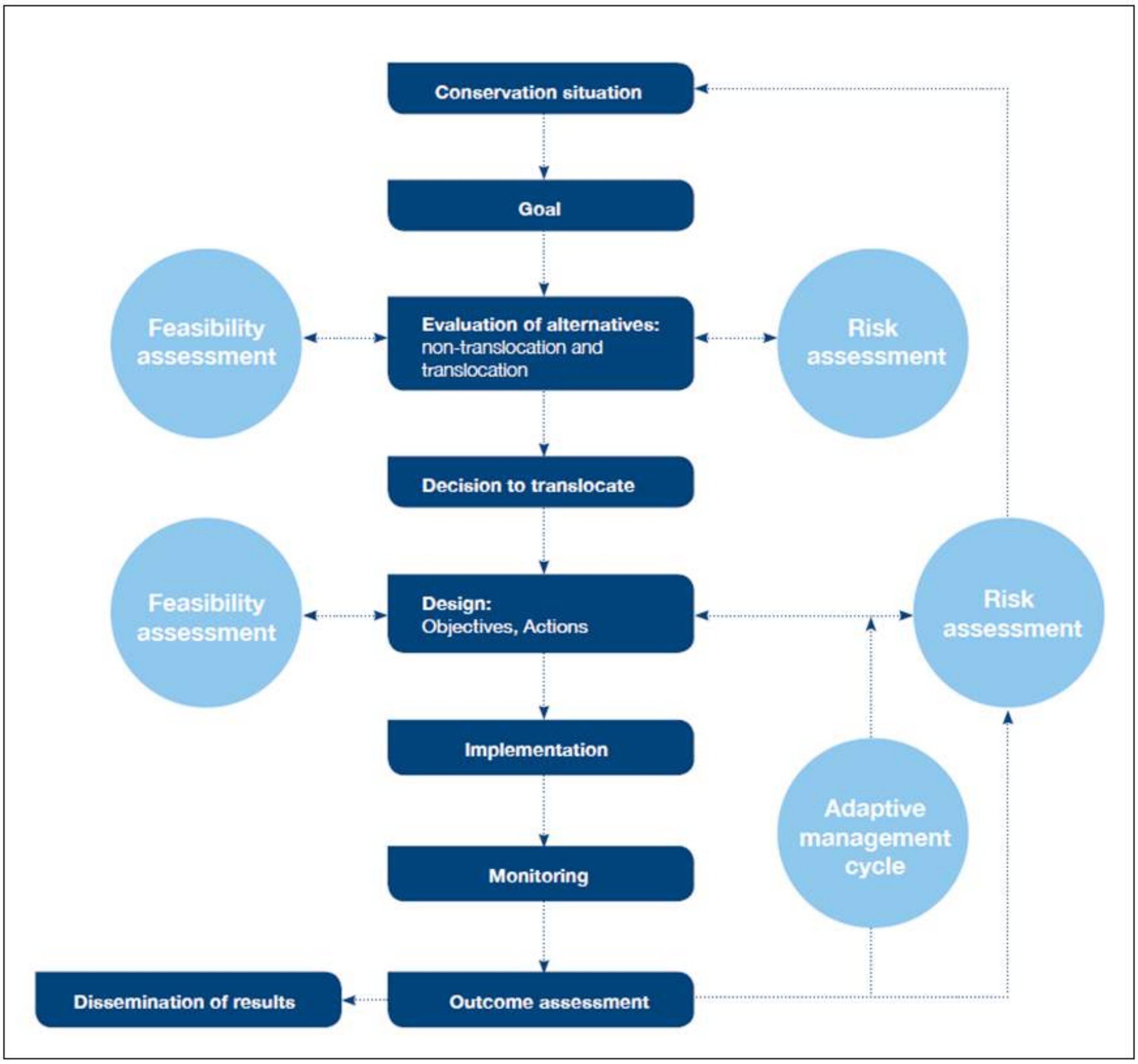


Fig. 2.10. The conservation translocation cycle (Hayek *et al*. 2016)

The types of translocation most relevant for conservation are ‘population restoration’ translocations which occur within a species’ indigenous range. There are two types of population restoration: (1) reinforcement, in which animals are released into an existing population to increase its viability, and (2) reintroduction, in which a population no longer exists within the area and releases aim to re-establish a viable population.

The IUCN/SSC (2013) argued that, before a responsible and efficient programme of reintroduction or translocation can be designed, it is important to make a thorough evaluation of the threats to a species’ persistence. This includes considering its classification, life cycle and ecology.

With regard to the Dorcas gazelle, Stanley-Price (2016) reports that there have been a number of reintroduction programmes at various times and in different places across its range, including in Tunisia, Morocco and Senegal (see Fig. 2.2 on

p. 17). He states that the Dorcas gazelle is the only reintroduced antelope whose numbers in the wild exceed those in captivity.

An example of a semi-captive breeding programme for Dorcas gazelle can be found in the Orbata Natural Reserve (ONR) in central Tunisia. According to SSIG (2002), the population increased from 30 animals in the founding population to over 250 individuals.

Gilbert (2011) argues that, although the benefits of captive breeding are generally recognised, it is significantly more expensive than conserving species in their natural habitat and it may also divert resources from *in situ* conservation projects. Gilbert (2011) also suggests that certain species cannot be successfully bred in captivity. Furthermore, some adapt to captive conditions, leading to transformations in the defining features of a species, both in terms of morphology and behaviour, and this can threaten their integrity as a species. Gilbert (2011) also stated that genetic adaptation to captivity can cause serious problems for populations that are to be reintroduced to the wild. Furthermore, if a captive population is isolated, the average phenotype of the population may move away from that of the wild population. Consequently, when animals are reintroduced to the wild, their fitness may be compromised in comparison to those in the wild (Arnold, 1995).

Gilbert (2011) concluded that, either individually or in combination, these issues have the potential to lead to inadequacies in captive breeding and reintroduction programmes. On the other hand, studies by Abaigar *et al*. in 2013 and 2016 reported that a programme in Senegal has demonstrated that gazelle born and kept in captivity for several generations have the ability to recover their natural behaviours. They examined the social organization and demography of reintroduced Dorcas gazelle in the North Ferlo Fauna Reserve in Senegal. Twenty-three Dorcas gazelle which had been born in captivity were released into a fenced area in the North Ferlo Fauna Reserve in March 2009. Following 4 years of monitoring, the behaviour of the gazelle was seen to adapt progressively to semi-wild living conditions. Abaigar *et al*. (2016) found that released Dorcas gazelle can recover their natural traits if sufficient natural space and food are available. They suggested that this was an indicator of the success of reintroduction projects. Furthermore, the reintroduced gazelles were able to withstand the presence of predators, of which jackals are the most significant. They re-established natural social behaviours and were able to defend territories. A more recent study by

Abaigar *et al*. (2018) reported that, following their reintroduction into a Sahelian habitat in Senegal, the Dorcas gazelle had been able to maintain its adaptation to changing environmental conditions in its native habitat.

Taken together, the outcomes of the studies by Chammem *et al*. (2008) and Abaigar *et al*. (2013; 2016; 2018) provide some evidence that captive breeding programmes for Dorcas gazelle can be successful. Furthermore, Mallinson (2003) argued that captive breeding should include both *in situ* and *ex situ* methods, which in combination, achieve better outcomes for conservation or recovery and facilitate the longer-term viability of populations.

However, despite the success of some reintroduction projects, Gilbert (2011) pointed out that many species have failed to establish self-sustaining populations. This is particularly true in projects that have used captive-bred animals. Furthermore, Hogg (2013) warned that captive breeding alone will not provide the solution for the recovery of a species and should be integrated with other recovery activities.

No structured captive breeding programmes for Dorcas gazelle have been implemented in Libya with the exception of the El-Kouf National Park and the New Hisha Reserve which are not functioning well (IUCN, 2008). The present study will consider their potential as part of a wider conservation strategy.

2.8.3. Protected areas and reserves

Ford *et al*. (2016) argued that protected areas are frequently regarded as the best and fundamental tool for conservation and they are particularly crucial for antelope conservation. According to Knight *et al*. (2016), such areas should include a wide variety of habitats which are protected from the intrusion of non-native flora and fauna. They need to be established in such a way that it is possible for the target vulnerable species to endure in the long term and in the full range of structures that had previously existed in the area. It is also vital that social or political conflicts do not undermine the viability of such areas.

The past 50 years has seen the creation of many protected areas in the African savannahs. However, according to Ford *et al*. (2016), it is not practicable currently to rely only on such areas for the conservation of antelope. They suggested that human activity in and near parks can negatively impact on wildlife abundance.

Species which are '*Critically Endangered*' and '*Extinct in the Wild*' require intensive management *ex situ.*

In Libya, a programme was established in the 1970s to create a number of protected areas, across the country, administered by the Secretariat of Agriculture and the Wildlife Technical Committee (Khattabi and Mallon, 2001). The first phase was to establish several protected areas in the north of the country. However, this was never implemented, but, by 1978 certain protected areas had been established, the locations of which are shown in Fig. 2.2 on p. 17. They included the El-Kouf National Park (35,000 ha), situated 60 km north of the study area, where a small population of 15 Dorcas gazelle, introduced from Sudan, was established in 1991, and the New Hisha Reserve (100,000 ha), which contained about 150 Dorcas gazelles when it was founded (Khattabi and Mallon, 2001). Anecdotal evidence suggests that the population in El-Kouf National Park increased in the years prior to the conflict but was then either killed or escaped. Tripoli Reserve (700 ha) is a fenced area, situated 15 km south of the capital, which continues to hold captive herds of antelopes and other species. Dorcas gazelle may also occur in the Garabulli (8,000 ha), Sabratah (1,200 ha) and Sorman (1,250 ha) National Parks and Nefhusa Protected Area (20,000 ha) (Khattabi and Mallon, 2001). Zella Nature Reserve (100,000 ha) is situated in the south-western desert but is not known to contain Dorcas gazelle (Khattabi and Mallon, 2001). No recent information exists about these areas following the conflict in Libya, which is known to have devastated parts of them.

Outside the protected areas and national parks discussed above, the nature of the terrain in some places, especially areas of rocky ridges, may offer a measure of additional protection from motorised hunting for a number of species, including the Dorcas gazelle (Khattabi and Mallon, 2001).

2.8.4. Non-governmental organisations and private individuals involved in conservation in Libya

Although no international conservation organisations have operated in Libya since the conflict in 2011, a number of national organisations are involved in conservation work. According to Khattabi and Mallon (2001) the Libyan National Society for Wildlife Conservation has been involved in wildlife conservation activities since 2000 and to the knowledge of the present author, still continues today. The Life Organization for Wildlife and Marine Protection was established in 2005 and has three branches throughout Libya with 650 active members and is taking an increasing role in wildlife conservation activities especially since 2013 (Alshalwi, 2016). Dorcas gazelle are commonly kept as pets, but the conditions they are kept in may not be appropriate, and the origins of these animals may be uncertain. Gazelles are kept as pets all over North Africa, except in Egypt, where they have become nearly extinct (Frost, 2014). In Libya, these pets are kept by many families and, if they are bred from domesticated parents, the practice is encouraged by the Ministry of Agriculture and Animal Resources. Agricultural Experimental Stations such as that of Sidi Mesri, Tripoli, keep a few selected healthy males to be used as stud animals for privately owned females, thus encouraging the breeding of gazelle from existing domesticated stock. According to Khattabi and Mallon (2001), most young gazelles in private ownership had been bought illegally after having been caught in the wild.

2.8.5. Strategic conservation management

Newby *et al*. (2016) argued that the range of challenges which antelope face in the Sahelo-Saharan region requires the adoption of a conservation approach that will link the captive, semi-captive, and wild populations across the world. In this way, there is a greater chance that the populations will become sustainable and the likelihood of protecting them will be increased. In view of the high number of threatened or endangered species, they call for the adoption of an integrated “One Plan Approach”, such as that advocated by Byers *et al*. (2013), which includes captive breeding, habitat restoration and reintroduction programmes.

According to Abaigar *et al*. (2013), the main current conservation interventions for the Dorcas gazelle, as for other endangered antelope in North Africa, are *ex situ* captive breeding programmes, reintroductions, the prohibition of hunting and the establishment of reserves and protected areas. Knight *et al*. (2016) argue that a range of management approaches are currently used in protected areas, including, providing additional water, constructing fences to allow for the controlled movement of animals, both wild and domestic, and ensuring that the land surrounding the protected areas is used in such a way that it does not undermine conservation activity.

The value of large protected areas (defined as >10,000 km^2) for the conservation of biodiversity has been widely acknowledged and the management interventions required are generally minor. However, most protected areas across the world are smaller than this (Chape *et al.* 2008). Knight *et al*. (2016) considered that these smaller protected areas usually need much more in the way of active management because habitat diversity is lower and ecological processes do not fully function. Despite this, conservationists try to replicate the outcomes of fully functioning ecological processes.

According to Knight *et al*. (2016), in order to achieve viable antelope populations, particularly in the smaller protected areas, a wide range of management tools are required. In addition, they argue that it is important to compensate for the restricted ecological processes and reduce conflict in the local community.

2.9. Chapter summary

The information contained in this review of the relevant literature will be used in the specific elements of this study. The questionnaire used with local stakeholders and international conservation experts regarding the status of the Dorcas gazelle in Libya was designed taking into account themes identified in the literature. Some of the methods identified and discussed in this literature review inform the design of the field surveys based on distance sampling. The genetic analysis draws on previous studies which used mitochondrial DNA (mtDNA), specifically the cytochrome b gene, to investigate the haplotype profile of Dorcas gazelle populations in the study area. This also provides the justification for the adoption of the research methods used in data collection. Finally, the conservation actions proposed are based on relevant and successful actions identified in the literature to create a viable conservation strategy appropriate to the study area and which, it is hoped, may have more general application.

Chapter Three: Site description

3.1. Geographical location of the study area

3.1.1. Geographic and demographic information relating to Libya

Libya is located in the Maghreb Region of North Africa. It is the fourth largest country in Africa in terms of area, occupying approximately 1.760 million km^2 (Saad *et al*. 2011). Libya is bordered to the north on its long coastline by the Mediterranean Sea, and by Egypt to the east, Sudan to the southeast, Chad and Niger to the south, and Algeria and Tunisia to the west. The human population is estimated to be between 6,400,000 and 6,500,000 (CIA, 2016). Historically, Libya comprised three main provinces: Tripolitania, Cyrenaica and Fezzan (Sunderland and Rosa, 1976). Tripolitania is the north-western corner of the country. The Sahara Desert covers all the province of Fezzan and the southern part of Cyrenaica. The latter is the largest province, covering the entire eastern half of the country (Hegazy *et al*. 2011). It includes Aljabal al Akhdar, known in English as the Green Mountain area, which is an upland plateau rather than the name of a discrete mountain (a mountain range along the northern coast of north eastern Libya). It lies north of the study area (Fig. 3.1).

Fig. 3.1. Map showing the location of Libya in North Africa. Its provinces and two main cities are identified in relation to the study area (based on Google Maps, 2017)

The dominant geographical feature of Libya is the Sahara Desert. Narrow strips of more fertile land are found along the north western and north eastern coasts and these contain most settlements and most of the human population. Between these two strips lies the barren desert coast of the Gulf of Sidra (Fig. 3.1). Inland from the two coastal strips, a series of hills, steppes, and escarpments gives way to semi-desert and then desert. In the eastern coastal area, the Green Mountain area reaches an elevation of 865 m and receives the highest rainfall in the country, about 500 mm/year (Simpson and Hunt, 2009).

3.1.2. Location of the study area

The study area is located in north east Libya to the south of the Green Mountain area (Fig. 3.2). Geographically the study area includes Kwlan, Wadi El Mahaga, Ceede Muhamed Hamri, Suluntah, Candula and Mrawah in the North, and Am Algazallan, Bulat Mhraz, Bulat Borkaes and Bulat Alraml in the south. The study area is bordered to the east by the El Mekhili area, and to the west by Taknis village and the Al Kharoba area. The study area has no protected areas or nature reserves.

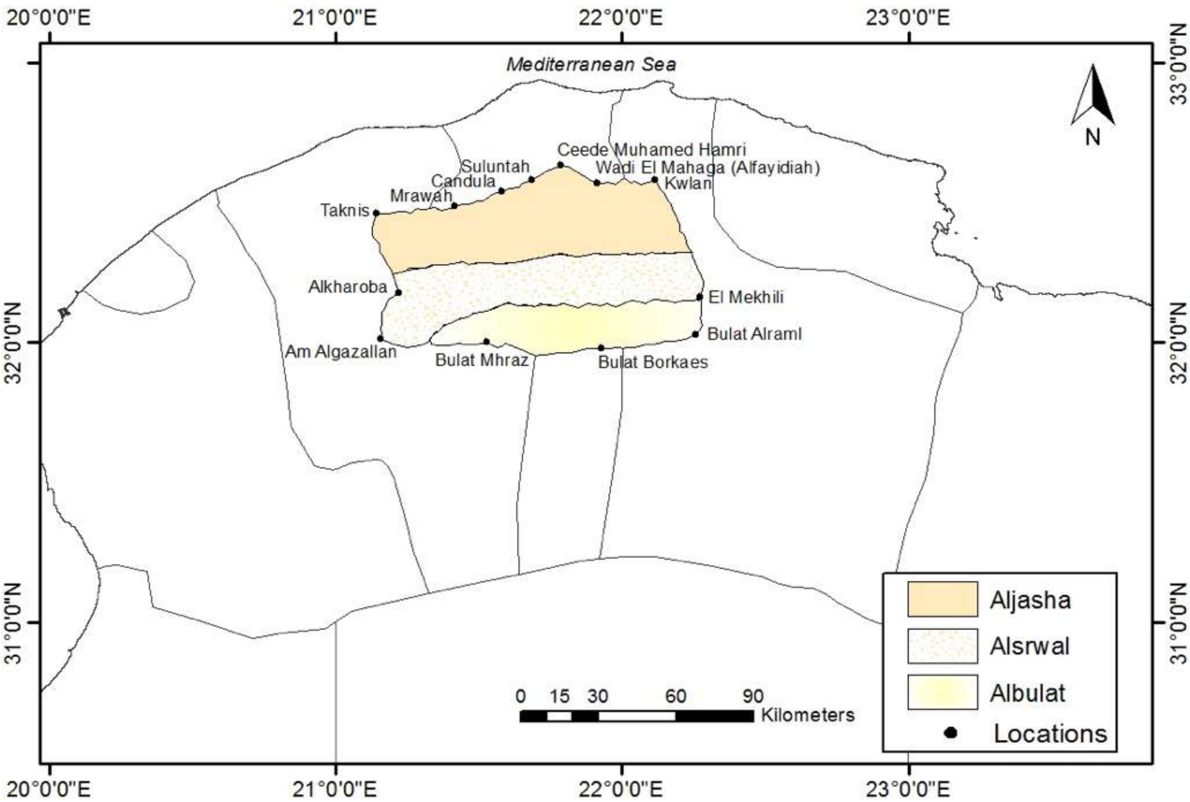


Fig. 3.2. The study area including the Aljasha, Alsrwal and Albulat areas (created by the author using ArcGIS based on an image from Google Maps)

The study area lies between latitudes 32°33’ and 31°45’ N, and longitudes 22°21’ and 21°04’ E. The estimated size is almost 16,700 km^2 and the human population is estimated to be approximately 600,000 (CIA, 2016). To the south of the Green Mountain area, the elevation decreases from a maximum height of 880 m to 150 m above sea level. The region directly south of the Green Mountain area is called the Aljasha area. Residents also call it by a variety of local names such as Amkabal and

Aldaher. To the south of this is an area known as Alsrwal and further south lies a flat area known as Albulat (Fig. 3.2).

This area was selected for several reasons. First, previous investigations (Algadafi, 2007) had shown that Dorcas gazelle still occurs here. Second, there are no recent studies related to Dorcas gazelle in this area. Third, there has been no investigation of how legislative policies and conservation programmes are being implemented in this area.

3.1.3. The Aljasha area

The Aljasha area is situated to the immediate south of the Green Mountain area and slopes south towards the Alsrwal and Albulat areas. The land surface is very complex and covered in most part with pieces of broken rocks and gravel. There is a detailed topography of many small and large deeply-incised valleys in close proximity to each other (Plate 3.1). The area covers 2500 km^2 of an undulating, stony plateau, with a highest altitude of about 613 m above mean sea level. The plain is interrupted by many dry valleys that run from north to south and carry seasonal water into the Albulat. Boulder fields are abundant in the study area. The area is classified as semi- desert (Awami, 1997), receiving less than 30 mm of precipitation annually. The rainy seasons extends from October to December and from January to April. Alkabbar shrubs (*Capparis spinosa*), *Haloxylon salicornum* and *Retama raetam* are the dominant plant species in the area (Plate 3.2).

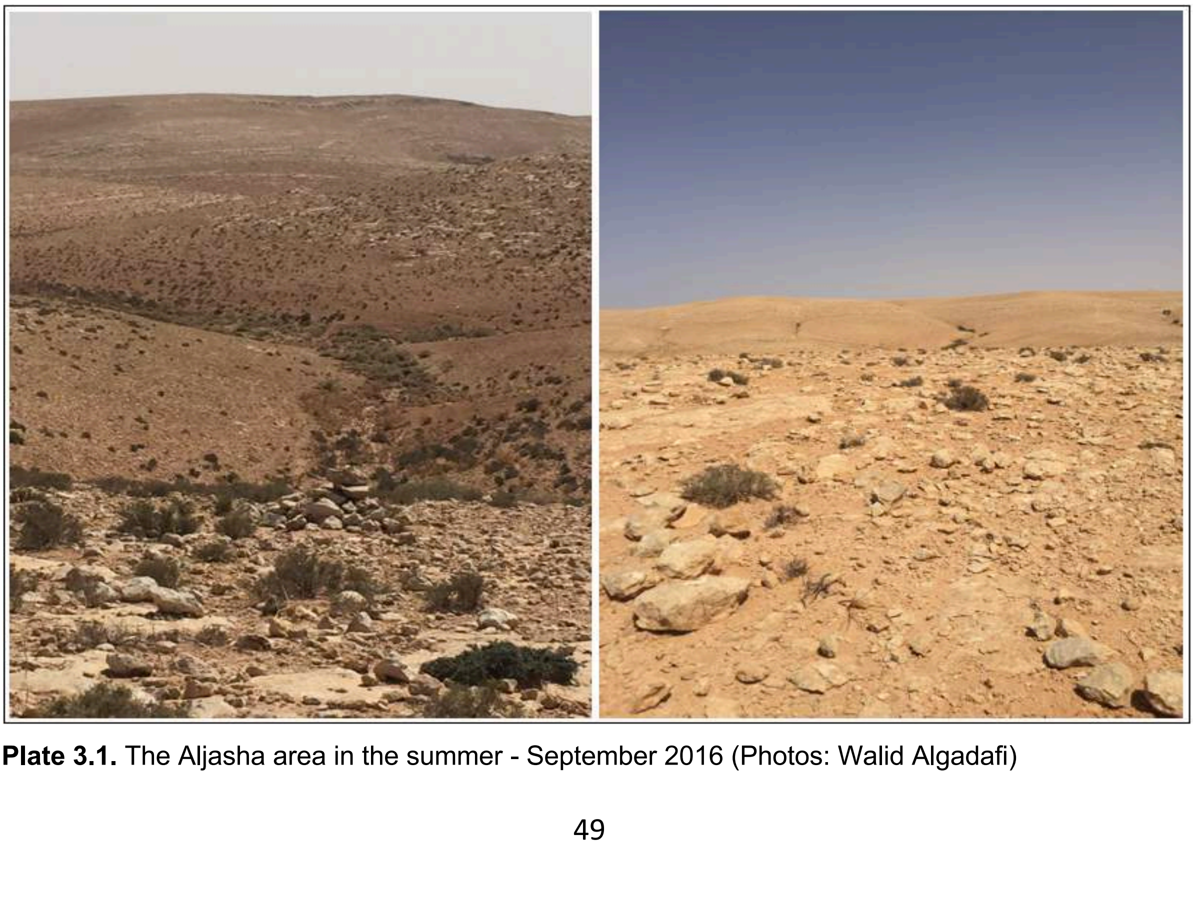


Plate 3.1. The Aljasha area in the summer - September 2016 (Photos: Walid Algadafi)

Plate 3.2. The main shrubs in the Aljasha study area (Photos taken in August and September 2016 by Walid Algadafi)

3.1.4. The Alsrwal area

The Alsrwal area is situated south of the Aljasha area. Here the terrain is very similar to the Aljasha area. The Alsrwal area slopes south towards the Albulat area. The estimated area is 2235 km^2 with the highest altitude being about 402 m above mean sea level. As it is more desert-like than the Aljasha area, there is reduced vegetation cover, but a range of plant species exists (Plate 3.3), with the shrub *Peganum harmala* being the dominant species in the area.

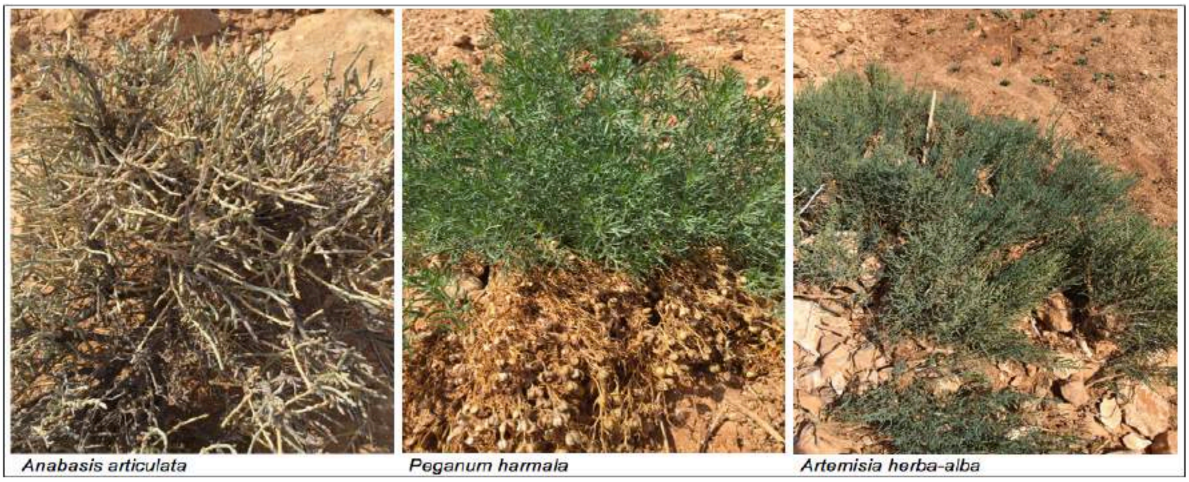


Plate 3.3. The main shrubs in the Alsrwal study area (Photos taken in August and September 2016 by Walid Algadafi)

3.1.5. The Albulat area

To the south of the Alsrwal area is a flat area known as Albulat, lying at N 32^o 21.287’, E 20^o 58.800’. Here, there are four large depressions which fill with rain water in the wet season but are dry in the summer. They are known locally as Bulat Alzalk, Bulat Alraml, Bulat Mhraz and Bulat Borkaes (Plate 3.4). The vegetation in this area is very limited, with the dominant plant species being *Cyperus conglomeratus*.

Plate 3.4. The Albulat area (Bulat Alraml) in September 2016 (Photos: Walid Algadafi)

3.2. Physical description

3.2.1. Geomorphology and topography

The study area is divided by a large number of valleys that vary in depth and length. In the north, they are oriented towards the sea while, towards the south, many are oriented to end in the desert and are linked to the areas of temporary water that are scattered throughout this part of Libya.

The topography of the area has a great effect on natural vegetation distribution. The low lands receive more water through runoff after rainfall. As a consequence, the resulting valleys provide protection against wind and human activities, and act as havens for many wildlife species.

The study area has experienced thousands of years of erosion resulting in a shallow soil profile over carbonate bedrock with stones and gravel on the surface. In the north of the study area there is *terra rosa* (red clay soil) and in the south the soil is yellow. It is mostly neutral or slightly alkaline in pH (El-Barasi *et al*. 2013).

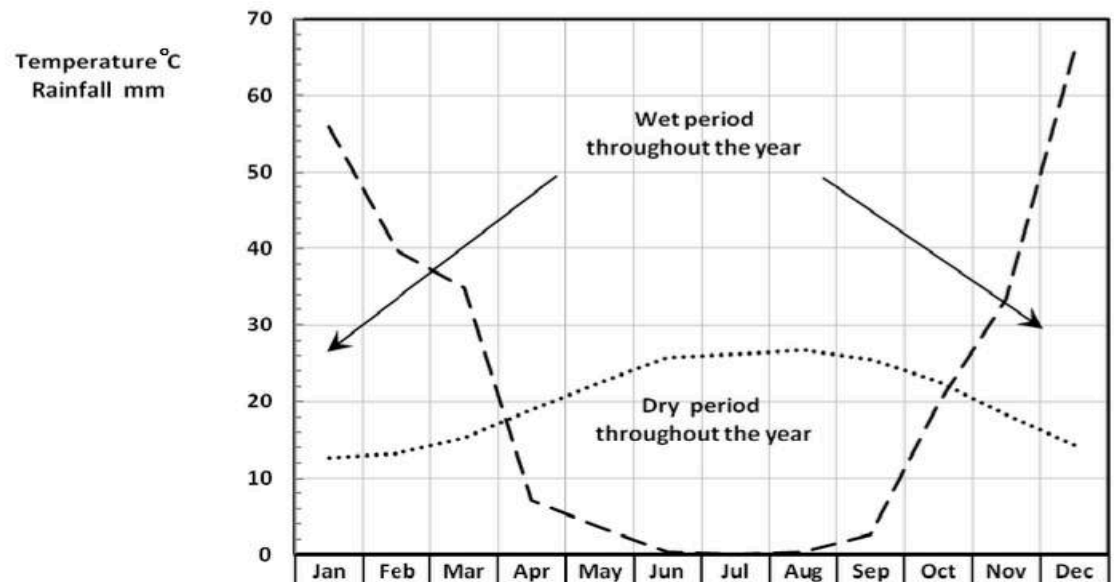
3.2.2. Climate and weather

The climate of Libya is influenced by contrasting Mediterranean and Saharan climates. As a result of the duration of the annual arid period, the climate of the study area can be classified as semi-arid.

El-Barasi *et al*. (2013) reported that the Green Mountain area has the highest rainfall in Libya, with an average of about 500 mm/year. However, rainfall is irregular with around 69% falling during the winter season from October to February, and the driest period of the year being from April to September. The rate of precipitation decreases to the south, east and west, where the average rain fall is about 270 mm/year. This rate continues to decrease to the south. The desert areas receive rates of less than 50 mm/year. The lower rainfall in the southern regions of the study area is reflected in the characteristics of the vegetation and soil. The vegetation is less dense and diverse in the southern than in the northern areas (El-Barasi *et al*. 2013).

The climatic data also shows that the months of June, July and August are the hottest months of the year when temperatures often exceed 35°C, while the months of December, January and February are the coldest months with temperatures sometimes falling to 0°C. The average annual temperature in the Green Mountain area is about 17°C and in the study area to the south, it is 20.1°C. The rate of evaporation exceeds 2,000 mm/year (El-Barasi *et al*. 2013).

The climate diagram (Fig. 3.3**)**, based on data from the Benina meteorological station in North East Libya, shows that December and January are the wettest period of the year. February, March and November are semi-humid periods. October is semi-dry, while the months from April to September represent the dry period. In spring and autumn, a hot, dusty, strong wind called '*Ghibli*' blows from the desert in the south, filling the air with sand and dust and raising the temperature to over 50°C in places. These strong *Ghibli* winds are a major erosion factor, transferring a large amount of sand from the Sahara Desert to the northern parts of Libya (El-Barasi *et al*. 2013).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
······· Average temperature	12.7	13.2	15.2	18.9	22.5	25.8	26.2	26.7	25.5	22.7	18.2	14.3
— — Average Rainfall	55.9	39.8	34.8	7.1	3.6	0.3	0.1	0.3	2.6	19.9	33.4	65.7

Fig. 3.3. Average climate data for the period 1950-2004 from the Benina meteorological station (El-Barasi *et al*. 2013)

3.2.3. Water resources

At least three ephemeral, free-standing pools of water created from rainfall and surface run-off are found in the southern most sectors of the study area at certain times of the year. A few species of small wading birds and small groups of white storks (*Ciconia ciconia*) are associated with these pools. Larger bodies of water likely to flood on an annual basis are frequent in the central wadi El Mahaga in the north of the study area. These are characterised by extensive stands of *Ziziphus lotus* and other shrubs (Plate 3.5). There are no permanent rivers, but the many wadis in the north of the study area carry water temporarily following infrequent heavy rain (Khattabi and Mallon, 2001).

Plate 3.5. Temporary wetlands in the Wadi El Mahaga with little egret (*Egretta garzetta*) photographed during the survey of the study area (August and September 2015. Photos: Walid Algadafi)

3.2.4. Human activities in the region

The study area is in a significant pastoral area. There are intensive human activities in the area, mainly in the form of animal rearing and herding, and agriculture, especially the cultivation of fruit and cereals. It has been estimated that there are in excess of one million sheep, goats, cows and camels (El-Barasi *et al*. 2013) which has led to overgrazing. There is also increasing use of mechanical equipment, such as tractors and ploughs (El-Barasi *et al*. 2013).

3.2.5. Habitats

The study area includes distinct habitats, characterised by broad valleys of sand, gravel, stone and large boulders. The landscape comprises a semi-desert system of arid valleys and plateaux, with a mix of grasses, shrubs and small trees (Plate 3.6, a, b and c). The south of the study area has a more Saharan character, with no significant vegetation cover (Plate 3.6, d).

El-Barasi *et al*. (2013) reported that this area of Libya contains species of *Retama*, *Artemisia*, *Asphodelus*, *Stipa*, *Pistacia*, *Zizyphus*, and *Arthrophytum*. Vegetation is mostly confined to wadi beds and depressions where a few trees and shrubs can be found, including *Colligonum* sp., *Tamarix* sp., *Aristida* sp., *Alhagi* sp. and *Acacia raddiana*, *A. ehrenbergiana*, *A. tortilis* and *Citrullus colocynthis*, which provide a valuable source of food for wild herbivores. The grass *Panicum turgidum* is also present in the region.

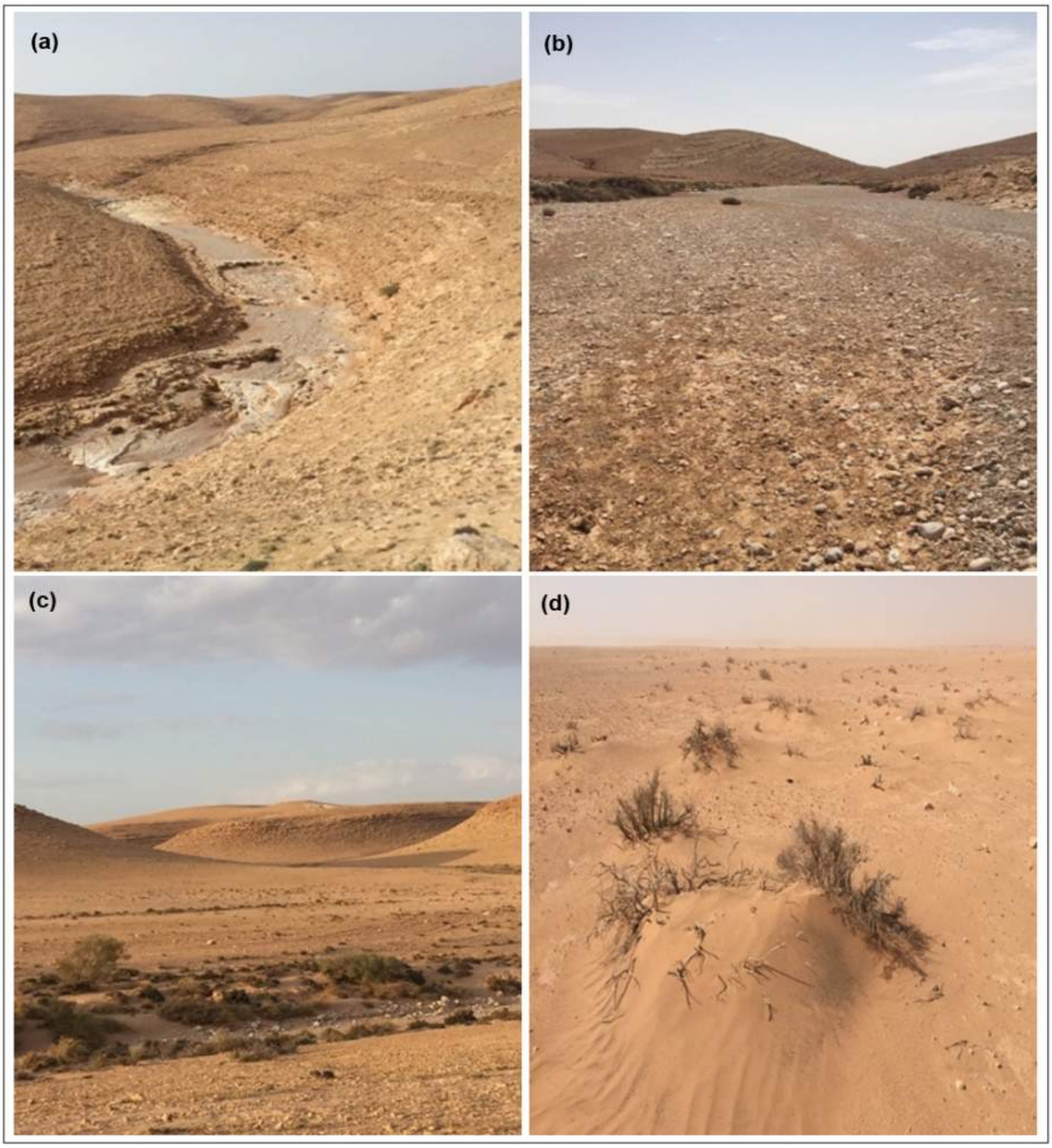


Plate 3.6. Habitats photographed during the survey of the study area, August and September 2016. a: a wadi; b: hilly terrain with rocks and boulders; c: a transitional, semi-desert landscape; d: desert terrain with *Cyperus conglomeratus* (Photos: Walid Algadafi)

3.2.6. Flora (vegetation) in the region

In the study area, the vegetation mostly consists of shrubs which give permanent cover. During the rainy season, annuals predominate. The vegetation in the area is influenced by the harsh climate, very varied topography and poor soil conditions, as well as the increasing impact of human activities. In the northern part of the study area, the land is covered by vegetation, of which *Juniperus phoenicea* trees are the most prevalent. This vegetation gradually thins out to the south and disappears, in parallel with changes in the topography.

The northern areas are also richer in phanerophytes species, such as *Acacia* spp., *Juniperus phoenicea*, *Pistacia lentiscus*, *Olea europaea*, *Rhus tripartita*, *Rhamnus lycioides* and *Lycium europaeum* (El-Barasi *et al*. 2013). However, in the wadis and depressions, there are a range of species, including *Retama raetam*, *Sarcopoterium spinosum*, *Artemisia herba-alba*, *Euphorbia falcata*, *Ziziphus lotus*, *Thymus capitatus*, *Phlomis floccosa*, *Atriplex halimus* and *Asphodelus microcarpus*. In plateau areas, the most common species are *Haloxylon scoparium*, *Anabasis articulata*, *Thymalaea hirsuta*, *Suaeda vera*, *Deverra tortuosa* and *Peganum harmala*. Annual growth happens only during the rainy season, with the appearance and abundance of the vegetation changing from year to year according to the amount and frequency of precipitation (El-Barasi *et al*. 2013). The shrubs and trees noted during the survey, and some of the more significant plant species recorded, are illustrated in Plate 3.7.

3.2.7. Fauna in the region

In addition to the Dorcas gazelle, notable among the mammals are *Canis aureus, Hyaena hyaena, Lepus capensis arabicus, Hystrix cristata, Hemiechinus auritus* and *Jaculus jaculus.* There is also a highly specialised bird fauna including species such as *Alectoris barbara* and *Chlamydotis undulata*. Reptiles including *Cerastes vipera, Testudo ibera, Varanus griseus, Lecerta muralis* and *Mabuya vittata* are also present. In addition, this region is increasingly used as permanent pasture for camels, as well as for ruminants, including cattle, goats, and sheep (Awami, 1997). Only a few studies of the mammals of Libya have been undertaken, all limited in nature, and consequently the status, distribution, and biology of most species are not well known.

Plate 3.7. A selection of plant species photographed during the survey of the study area (August and September 2015) (Photos: Walid Algadafi)

Chapter Four: Questionnaire surveys to investigate the perspectives of experts and in-country stakeholders regarding the conservation status of Dorcas gazelle

4.1. Introduction

The aim of this chapter is to report the findings from questionnaire surveys of the opinions of both international conservation experts and local stakeholders regarding the conservation status of Dorcas gazelle. These surveys were conducted to achieve the first and third objectives of the study with regard to the provision of data on the distribution and relative abundance of the Dorcas gazelle, its main threats and appropriate conservation measures. The views of these two key groups will help to understand the current status of the Dorcas gazelle in the study area. The findings will be used to inform proposals for conservation efforts within the study area in North East Libya.

This Chapter is divided into two parts. The first part presents the opinions of international conservation experts on the current status and conservation of Dorcas gazelle in and outside Libya. The second part presents the perspectives of local stakeholders on the current status and conservation of the Dorcas gazelle in the study area. Additionally, information from local stakeholders was gathered as to the whereabouts of Dorcas gazelle populations in the study area to inform the locations used for the fieldwork and to allow for more focused field research which is discussed in Chapter Five.

The review of the limited relevant literature in Chapter Two demonstrated that there was a clear need to take into account the impact of human activities on the Dorcas gazelle when investigating its conservation status. To the researcher's knowledge, no studies, other than Algadafi *et al*. (2017), have been published which contain the views of local stakeholders on this species and there is no published information relating to the study area. International conservation organisations work with a diverse array of stakeholders in order to achieve their objectives (Crandall *et al*. 2018). It was therefore, considered important to attempt to gather the views and experiences of people who live in, or close to, the study area and engage with the gazelle in their daily lives, along with those of people involved locally in wildlife conservation. Specifically, it was considered vital to consult those involved in hunting, whose perspectives have never been included in similar research in Libya. Qualitative surveys are useful tools in conservation efforts and the results can be used to inform policy and management decisions by providing data about people's perceptions, level of knowledge, values and attitudes towards environmental issues and concerns (Schultz *et al*. 2005). A number of studies which used questionnaires for a similar purpose, such as Sillero-Zubiri *et al*. (2013) and Dutton *et al*. (2015), were discussed in the literature review and, thus, the adoption of this research methods for the collection of data can be justified.

The results presented in this chapter will contribute to the effective conservation of the Dorcas gazelle by enabling the perspectives of international conservation experts and local stakeholders to be incorporated into the larger investigative framework.

4.2. Methodology

Gathering data about people's opinions concerning a range of issues relating to the Dorcas gazelle was a vital aspect of this study and for this purpose, a qualitative questionnaire survey was considered an appropriate method. Questionnaires are precise and powerful tools for collecting carefully-focused information from a large number of people (Newing *et al*. 2011) and give the researcher the highest level of control over the form and content of the data collected. According to White *et al*. (2005) questionnaires are the most widely used social science method in conservation.

According to Reed (2008), a crucial element in such surveys is to clearly identify the stakeholders who should be involved and use creative methods to engage with people and groups who may have completely different value-sets. The potential number of in-country respondents was expected to be high due to the large size of the target populations and the extensive boundaries of the research area. The choice of respondents with differing perspectives would inevitably influence the outcomes of the survey. The sampling procedures used are discussed in Section 4.2.1. It was impossible to ensure that every member of the target populations, including hunters and local residents, had an equal chance of participating. However, the number of experts with local knowledge was much lower and an attempt was made to identify all who may be able to make a valuable contribution.

Reliability and validity were the core concerns of this study. In qualitative studies, Hammarberg *et al.* (2016, p. 500) suggested that credibility should be the criterion for evaluating 'truth' or validity. They further stated that such studies can be regarded as credible if the "results, presented with adequate descriptions of context, are recognizable to people who share the experience" (p. 500). The researcher can improve credibility through reflection on his/her own impact on the study, triangulation and a full discussion of the process used to interpret the data. To promote triangulation, this study employed questionnaires to gain data from both international conservation experts and a range of local stakeholders (hunters, those interested in wildlife conservation and local residents), and a field survey to assess the current status and population trends (by estimation of abundance) of the Dorcas gazelle in the study area.

With regard to whether the results of such studies can be generalised to other contexts, Hammarberg *et al.* (2016, p. 500) argued that studies need to fulfil the criterion of "applicability". This can be said to happen if the findings "fit into contexts outside the study situation and when.…researchers view the findings as meaningful and applicable in their own experiences". These considerations have been borne in mind in the design of the present study and in the presentation of the findings.

4.2.1. Sampling process

Sampling is the process whereby part of a population is selected for research. A sample is defined as a group of respondents from whom important information can be obtained about a study and that information has to reflect the population's views (Webster, 1985). Sampling can be divided generally into two main types:

1. Probability sampling: (random sampling; systematic sampling; stratified sampling).

2. Non-probability sampling: (convenience sampling; judgment sampling; quota sampling; snowball sampling).

Questionnaire surveys are usually used to collect data relating to a set of pre-defined variables from a large number of people (typically over 100) (Newing *et al*. 2011). Matthews (2006) points out that in qualitative research, the sample size tends to be small, due to the large volume of gathered data. However, the aim of the sampling design in qualitative research should be to make sure that enough data is gathered to give an accurate understanding of the issues under investigation and the different perspectives that are present in the study population (Newing *et al*. 2011).

The following sections discuss the techniques used in the selection of respondents for this study.

4.2.1.1. Selection of international conservation experts

Seeking the views of experts through the use of questionnaires is established practice in the field of conservation studies, for example Gusset and Dick (2010) and Emre Can *et al*. (2014). It was, therefore, decided to approach a range of experts to determine if they had any relevant, recent unpublished information relating to the Dorcas gazelle in Libya because many of the published studies about the status and conservation of the Dorcas gazelle do not relate specifically to Libya and those that do were published before the conflict which began in 2011. Their views on the best approach to conservation in the specific circumstances of modern-day Libya were considered important.

For the purpose of this study, international experts are defined as scholars who have published articles relating to the preservation of gazelle and those who had been involved in studies related to the Dorcas gazelle during the period 1990 – 2015. The experts were identified through the websites of the Sahara Conservation Fund, the Experimental Station of Arid Zones (EEZA) and the IUCN, as these are the major specialist organisations concerned with the study and conservation of antelopes in the region. Thus, the first questionnaire was used to seek the opinion of international conservation experts, of whom a total of 40 were identified and comprised the target population and questionnaires were sent to them all. Full details about the experts to whom the questionnaire was sent can be found in Appendix 1. Anonymity was offered but none of the experts requested it.

4.2.1.2. Sampling methods for the selection of local stakeholders

According to Thompson (1999), the type and size of the sample should be based on the purpose of the study. It was impossible to ensure that every member of the target populations, including hunters or local residents, had an equal chance of being selected due to the large size of these populations in the vast research area and the cost and time required. Therefore, the sample of local stakeholders was selected using convenience sampling, defined by Etikan *et al*. (2016, p. 2) as:

> a type of non-probability or non-random sampling where members of the target population that meet certain practical criteria, such as easy accessibility, geographical proximity, availability at a given time or the willingness to participate, are included for the purpose of the study.

As they point out, this method has the obvious disadvantage that the researcher cannot be completely certain that the sample is representative of the population as a whole and may consequently lead to bias. This is carefully considered when discussing the ability to generalise from the results of these surveys.

It was intended that respondents should provide data relating to non-documented facts and their perceptions of actual events. According to Newing *et al*. (2011), it is important to make sure that the sample selected has some information about the issues raised in the survey questions. The sample of local stakeholders was selected for this study because of their knowledge or experience of the Dorcas gazelle in the study area. In addition, several international experts recommended that information on the Dorcas gazelle should be collected from members of the population who live in/around the study area.

An initial sample of 15 local stakeholders, known personally to the researcher, was approached to form a pilot group. They had different educational levels and comprised different catagories of the target population, and they did not form part of the final sample. Information was gained from this initial sample about the existence of a monthly meeting of the hunting community, and the next was to be held on 3 September 2015 in Al Bayda city, approximately 50 km to the north of the study area. The researcher attended this meeting where 75 local stakeholders from around the study area agreed to participate in the study.

A further 30 respondents were identified using a snowball sampling technique from contacts supplied by those attending the meeting. The ‘snowball technique’ involves asking respondents to put the researcher in contact with one or two more individuals (Morgan, 2008). This technique can be especially useful when members of the community are hard to find (Morgan, 2008; Crandall *et al*. 2018). The remaining 25 respondents were selected on an *ad hoc* basis during field work from people who lived in the study area, making a total sample size of 130 for the 2015 questionnaire of in-country stakeholders.

The sample for the second questionnaire survey of in-country stakeholders in 2016 was identified at another meeting of the same hunting community which was held on 7 August 2016, also in Al Bayda city. The total sample size for this questionnaire was 100. All respondents defined themselves as being interested in hunting or wildlife conservation, or they were residents of the local area and none of them were known personally to the researcher.

White *et al*. (2005) stated that, in order to reduce bias and maintain high reliability, the sampling frame should be as comprehensive as possible. In this study, it comprised attendees at a meeting, those selected through snowball sampling and an *ad hoc* group of residents from the local area.

4.2.2. Design and administration of the questionnaires

Open questions were used in the questionnaire sent to international conservation experts in order to obtain qualitative data. Both open and closed questions were used to collect information from local stakeholders. The use of both types of question in combination can provide a greater depth of data and assist in obtaining both qualitative and quantitative data.

4.2.2.1. Experts questionnaire

A questionnaire was used to obtain qualitative data relating to the opinions of international conservation experts. It was also hoped that they may be able to assist in framing certain questions to be put to local stakeholders in the in-country questionnaire. The questionnaire comprised of 19 questions divided into four sections: i) distribution and population numbers of Dorcas gazelle (4 questions relating to Research Question 1); ii) threats to Dorcas gazelle in Libya (2 questions relating to Research Questions 2 and 3); iii) conservation and management of Dorcas gazelle in Libya (9 questions relating to Research Question 5); and iv) distribution, threats and conservation of Dorcas gazelle in areas other than Libya (4 questions for comparative purposes). The questionnaire included open questions with a space for respondents to add their own views and comments (the questionnaire is included in Appendix 2). According to Crandall *et al*. (2018), open-ended questions allow respondents the freedom to answer in their own words and are used in this study to collect more detailed responses than closed questions alone allow.

The questionnaire was sent electronically in March 2015 with a return deadline of the end of June 2015 set for its completion and electronic return. A covering letter was sent along with the questionnaire (see Appendix 3).

4.2.2.2. Local stakeholders' questionnaires (In-country questionnaires)

A questionnaire was developed to be used in-country in order to establish respondents' views about the current status of Dorcas gazelle in the study area, their attitudes towards human-wildlife conflict in general and with particular reference to Dorcas gazelle. It was translated into Arabic and piloted (in July 2015) on a sample of 15 respondents known personally to the researcher as individual residents in, or around, the study area and having an interest in the Dorcas gazelle.

According to Sandbrook *et al*. (2013), the pre-testing of questionnaires on a small pilot group helps to identify and eliminate any potential problems. A pilot study can be defined as a feasibility study or a preliminary study to verify the efficiency of the tool to be used for data collection, to identify weaknesses in the proposed questions and try to address them before any subsequent steps (Sheskin, 1985). Relevance and accuracy are the prime considerations when creating reliable surveys. These two principles guided the development of the survey questions (Iraossi, 2006).

The aim of the pilot study was to ensure that the questionnaire was clear, user-friendly and comprehensive. A questionnaire reliability test was conducted using Cronbach's Alpha, which is “commonly used to examine the internal consistency or reliability of summated rating scales” (Vaske *et al*. 2017, p. 163). Some questions were deleted in the light of this test to improve reliability.

The questionnaire consisted of 21 questions (see Appendix 4). In addition to four questions numbered 18-21 relating to the personal profile of respondents, this questionnaire contained three sections corresponding directly to the research questions:

1. Knowledge, distribution, and numbers of Dorcas gazelle (four questions numbered 2, 3, 5 and 6 relating to Research Question 1, and four questions numbered 1, 4, 10 and 11 relating to knowledge and distribution of Dorcas gazelle);
2. Attitudes and threats to Dorcas gazelle and the reasons for them (four questions numbered 7-9 and 15 relating to Research Questions 2 and 3);
3. Conservation, management and damage control measures for Dorcas gazelle (five questions numbered 12-14 and 16-17 relating to Research Question 5).

Most of the questions were closed and offered limited response choices, although some of the questions were open-ended. In this way, the researcher was able to collect both qualitative and quantitative data. According to Newing *et al*. (2011) and Heyman (2011), closed-ended questions maximise the ease of coding responses and improve respondent cooperation whilst open-ended questions allow respondents the freedom to answer in their own words. The open questions provided more detailed information and aided in the interpretation of the closed-ended questions. Questions 8, 12 and 13 required a choice from a 5-point Likert scale where 1 = ‘strongly disagree’ and 5 = ‘strongly agree’. Respondents were provided with clear options (Saunders *et al*. 2009; Rigg and Sillero-Zubiri, 2010).

As recommended by Newing *et al*. (2011), the questionnaire started with questions that were straight-forward, unthreatening and interesting, so that the respondents were put at their ease and encouraged to continue, with the more difficult or sensitive questions coming later on when the respondent should be more engaged and relaxed. In addition, highly technical terms were avoided in the formulation of questions, so that respondents could understand them easily.

Certain questions were asked more than once in different forms for the purposes of triangulation to improve reliability and validity (Heyman, 2011). For example, both question numbers 1 and 2 asked about areas where the Dorcas gazelle inhabit, but they were framed in different ways to improve internal validity of the questionnaire.

An introductory statement on the purpose of the study and on the confidentiality of the responses was read to all potential participants. They were informed of the procedures to be used in the study and ethical issues were addressed (see section 4.2.3). Respondents were given the opportunity to ask questions about the aim and objectives of the research. To minimise bias and improve reliability, it was clarified that 'I don't know' is an acceptable answer (Newing *et al*. 2011). It was stressed that there were no right, or wrong responses and respondents were encouraged to give their honest opinions. A relaxed atmosphere was created to encourage participants to contribute effectively.

75 questionnaires were distributed at the meeting (held on 3rd August 2015) of the hunting community as discussed above, a further 30 questionnaires were distributed personally by the researcher to respondents in their own homes (also in August 2015) and collected later, with the final 25 questionnaires also being distributed personally by the researcher during field work in the study area. All questionnaires were completed individually. If respondents were illiterate, the questions were read to them and their answers were noted in hard copy. Any misunderstandings were explained, for example an explanation was given of the symbol used for percentages (%). The questionnaire took each respondent about 30 minutes to complete.

A further questionnaire was developed in 2016 in order to obtain the most recent information. The aim of this questionnaire was to gather any further specific information that was not available at the time of the previous survey in the summer of 2015. The questionnaire used in 2015 was amended to include only 10 questions. Six of them sought information about the numbers of Dorcas gazelles seen during 2016 (4 questions) and any specific hunting incidents (2 questions). The remaining 4 questions were about the profile of the respondents (see Appendix 5). Another meeting of the hunting community, referred to above was attended on 7 August 2016. At that meeting, a total of 100 questionnaires were distributed and completed by respondents, some of them were the same as those who had completed the questionnaire in 2015. As in 2015, they were distributed personally by the researcher.

4.2.3. Ethical considerations

According to the Social Research Association (2003), there has been a remarkable increase in attention paid to ethical considerations due to changes in the concept of human rights and the protection of data; all these changes seek to increase the level of ethical standards regarding how to deal with research participants. According to Saunders *et al*. (2009), the general ethical issues that should be taken into account are privacy, the voluntary nature of participation, consent, deception, confidentiality, anonymity, embarrassment, stress, harm, pain, objectivity and the quality of research. Furthermore, Gray (2004) noted that research respondents should not be harmed or damaged in any way by the research. Ethical issues arise at a variety of stages in many research projects (Bryman, 2006).

Ethical approval was granted by the Life Sciences Ethics Sub-Committee of the Faculty of Science and Engineering at the University of Wolverhampton for all of the questionnaire surveys. The researcher endeavoured to protect and respect the rights of all participants. In this study, the meeting with potential respondents was particularly sensitive and required consideration of the ethical issues raised above. All respondents were made aware of the following issues:

- Although the names of participants were recorded with their permission for future reference, it was emphasised that no names would be included in the analysis of the data.
- The data collected would be for the purposes of scientific research only.
- All responses would be confidential.
- The participants were free to answer the questions in their own way.
- Participants had the right to refrain from responding and withdraw at any time during the research.
- The information gathered would be kept securely in locked cabinets or password-protected electronic format, with access reserved for the researcher.

- All matters of a social or cultural nature would be respected and monitored since the researcher wanted to avoid any interventions that may affect the value and validity of the data.

4.2.4. Data analysis process

The data collected from the international conservation experts' questionnaire, gathered using a qualitative approach, were not analysed statistically owing to the narrative nature of the responses. Instead, a thematic analytical approach relating to the themes in the Research Questions was adopted. Nowell *et al.* (2017, p. 2) state that thematic analysis is "a method for identifying, analysing, organising, describing and reporting themes found within a data set", which, they argue, can provide "trustworthy and insightful findings".

The responses obtained from the in-country questionnaires were analysed using the Statistical Package for Social Sciences (SPSS) software Version 24 (IBM, 2017) to obtain descriptive data. The non-parametric chi-square test was also used to identify the relationships between age, education level, category of respondent and all variables. A T-Test (Paired Samples Test) was used to determine the difference between the number of gazelles that had been seen in the two periods of study (2011-2015 and 2016) (further details about these tests can be found in Appendix 6). Table 4.1 shows the analytical techniques used.

Table 4.1. Tabulation of tests/programmes, variables and objectives

Tests and Programmes	Variables	Objectives	Sources of information
Chi-square test	All variables	To identify the relationships between gazelle sightings and age, education level and category of respondents (if statistically significant). To investigate the relationship between age, education level and category of respondent and gazelle sightings, estimates of the decrease in Dorcas gazelle numbers, assaults and gazelle killed.	In-country questionnaires 2015 and 2016
T test analysis (Paired Samples Test)	The number of gazelle sightings	To determine the difference between the number of gazelles that have been seen in two periods of study (2011-2015 and 2016).	In-country questionnaires 2015 and 2016
ArcGIS	Locations inhabited by gazelles. Locations of gazelle killings	To determine the whereabouts of gazelles within the study area. To determine the location of gazelle attacks within the study area.	In-country questionnaires 2015 and 2016

Any results that were not statistically significant are commented upon but are not fully included in the analysis as they did not contribute further to the wider understanding of the respondents' views. Furthermore, the data collected from the in-country questionnaires in 2015 and 2016 were used to inform the development of maps (using ArcGIS) of habitat that is potentially suitable for Dorcas gazelle and the locations of sightings and hunting incidents to allow for more focused field research.

4.3. Results

4.3.1. The perspective of international conservation experts

A total of 13 of the 40 questionnaires distributed were returned with answers, giving an acceptable response rate of 32.5% (White *et al*. 2005). In follow-up communications, it became clear that all the experts who felt unable to complete the questionnaire had insufficient information and had not worked with Dorcas gazelle in Libya.

There were 4 sections in the experts' questionnaire and their responses to each section are summarised below (sections 4.3.1.1 – 4.3.1.4).

4.3.1.1. Distribution and numbers of Dorcas gazelle

The experts were asked about the location of Dorcas gazelles in the study area, their current numbers, historical numbers, and the size of the groups in which they tend to be found. They all agreed (n = 13) that Dorcas gazelle were formerly widespread, and the species was found over more or less all of Libya. All of the experts concurred with the information from Hufnagl (1972) and sources referenced in the IUCN's Antelope Action Plan Part 4 (Mallon and Kingswood, 2001). The information concerning Libya obtained from the experts related to a period after the Libyan revolution in 2011. In the questionnaire, all the respondents mentioned seeing pictures and information about thousands of killed Dorcas gazelle and Barbary sheep on "Facebook" posted by naturalists and wildlife conservationists. The first photos of massacres using 4 x 4 cars and military vehicles were taken in the south-western part of Libya, close to the Akakus region (see Fig. 4.7, p. 86). They also reported that the Algerian/Libyan border was a refuge area for all kinds of antelopes including, potentially, Dorcas gazelle.

One respondent stated that Dorcas gazelle were reported in the Jebel Uweinat area (see Fig. 4.7, p. 86) in south east Libya by explorers and travellers in the early-mid 20th century and are known to continue to occur in small numbers in that area. A handful of solitary individual gazelles had been seen and the respondent noted that tracks in vegetated valleys showed that there is a population of perhaps a few dozen animals living there and on the surrounding plains (primarily to the south of Green Mountain). Herds of 50 - 60 had been previously reported by Hufnagl (1972) and all the respondents referred to this information in their responses. However, they also stated that it is now impossible to estimate the total population size and they were not able to give an estimate as no systematic surveys had been conducted. Respondents were not aware of any recent reports or other information about the population numbers and there were no known methods of estimating these numbers. The evidence of the respondents about distribution, coupled with the supporting indications from social media, would suggest that, with increasing poaching, the gazelle groups tended to be extremely small.

To the combined respondents' knowledge, no population estimates had been published for the study area and no systematic surveys had been carried out on which to base any estimates. Respondents noted that Hufnagl (1972) did not give any estimates. The experts suggested that this lack of information about distribution and numbers of Dorcas gazelle should be explored with the local communities who may have further information. This was done in the in-country questionnaires discussed below.

4.3.1.2. Threats to Dorcas gazelle

The experts were asked about the main threats and challenges that face Dorcas gazelle populations in Libya, and in particular in the study area in north east Libya, historically and currently. They all agreed that the main threat to Dorcas gazelle in the wild has always been unregulated hunting, including unlimited poaching, and that such activity is unsustainable. In addition, three respondents noted that climate change may present a threat, as may the results of civil unrest, the loss of habitat due both to an increase in its use by domestic livestock and a degradation of range resulting from heavy livestock use. Another challenge is desertification, and the loss of suitable areas with moisture-bearing vegetation and shade which enable gazelle to survive in the dry season. Some respondents reported that local people have expanded their use of these areas now that they have been made available through the drilling of water wells (n = 2).

None of the experts had any data or information relating to the study area in the north-eastern part of Libya, but they suggested that it is likely to be suffering the same threats observed in other parts of Libya, especially the lack of state control and the mass killings of gazelle by humans.

4.3.1.3. Conservation and management of Dorcas gazelle

The experts were asked about the measures, current and historic, that affect the conservation and management of the Dorcas gazelle in Libya and in particular in the study area. The respondents were aware of very few measures currently being taken to conserve the Dorcas gazelle across its natural range in Libya (n = 13). Some protected areas had been created in different regions of Libya such as Nefhusa Protected Area, New Hisha Reserve and El-Kouf National Park (see Fig. 2.2, p. 17), and there had been some gazelle releases. Several respondents (n = 11) indicated that the IUCN's *Antelope Action Plan Part 4* (Mallon and Kingswood, 2001) was the best source of data. The respondents (n = 13) had no further detailed information and they were not aware that any monitoring had been undertaken. As a result of political unrest, the situation is unclear in Libya and conservation is not seen as a priority. Some small actions have been taken by some NGOs, such as awareness-raising and the breeding of specimens in captivity. The respondents (n = 13) stated that, from its inception, they have been following the activities of the Libyan Wildlife Trust, a Libyan NGO, which tries to share information and inform local and international opinion on the current situation relating to all wildlife, including threatened species. Action by local and national NGOs using a network of internet platforms is doing as well as possible, but the respondents had no further information about governmental resolutions or work in the field.

The respondents (n = 13) expressed the hope that, as there are now laws protecting Dorcas gazelle, any off-take will be sustainable. They stated the view that even the best management regulations are difficult to enforce and that until security is improved, there will be no control. All the experts stated that they had no data or information about any current measures that were being taken to conserve Dorcas gazelle in the study area.

The responses to the questions about the main priorities and/or opportunities for conserving Dorcas gazelle in Libya, and the viability of restoring numbers to historical levels, are summarised in Table 4.2.

Table 4.2. Respondents' view of the main priority/priorities and/or opportunities for conserving Dorcas gazelle in Libya, and the viability of restoring numbers to historical levels

Comments	No. of respondents (n = 13)	
	No	%
In the current situation of unrest and increasing poaching, captive breeding in different places in Libya may be a good solution while waiting for better conditions	13	100
Increasing environmental awareness through education programmes may lead to increased protection for the gazelle and this clearly needs to be an element in any effective conservation strategy	12	92.3
It is important to restore governmental authority with the help of local and civil society	11	84.6
It is important to establish political stability, a functioning administration and physical security. Unless Libya can be made to become a functioning state again, there are no opportunities. They saw little chance of this without outside intervention	10	77

The experts (n = 13) believed that, as there was no historical baseline for the number of Dorcas gazelle, it was necessary to assess their current status and develop an action plan to ensure that illegal hunting was controlled. They (n = 13) suggested that it should be possible to establish a viable population in protected areas if these are properly safeguarded.

The experts were asked about key organisations involved in the conservation of the Dorcas gazelle, worldwide and in Libya, and good examples from elsewhere in the world that could be used as models for the conservation and management of the Dorcas gazelle in Libya. They all (n = 13) stated that, with the exception of the Libyan Wildlife Trust, they were not aware of any organisations working in Libya at present. With regard to international organisations, the Sahara Conservation Fund (SCF) is regarded as the best-known conservation organisation in the Sahelo-Saharan region. It is dedicated to the survival of Saheleo-Saharan wildlife, but it is not currently working in Libya. Other organisations include the Convention on Migratory Species (CMS), the Sahelo-Saharan Interest Group (SSIG) and the IUCN Antelope Specialist Group. The Zoological Society of London also partners with organizations such as the SCF and sends personnel into the field to undertake surveys and other conservation activities.

When asked about the main obstacles to conservation of the Dorcas gazelle in Libya, all the respondents stated that they were unaware of all the main threats as they were removed from the situation on the ground. However, they were all certain that an improvement in security would help to restore wildlife to its natural habitats.

However, the experts believed that the main obstacles were uncontrolled hunting and poaching, as is the case in other North African regions within the Dorcas gazelle's range. Other obstacles included a lack of awareness (n = 12), political instability (n = 10), lack of security (n = 10) and the widespread availability of firearms (n = 13).

The respondents were asked if they were aware of any other research on this topic or of the existence of any data sets (current or historical) from Libya or elsewhere that would be useful. They responded (n = 13) that they were unaware of research or data in Libya and the request to participate in the current study was the first time they had become aware of a research interest in the Dorcas gazelle in Libya. With regard to data from elsewhere, they were aware of a number of articles and theses concerning the Dorcas gazelle. There is significant population data for Dorcas gazelle in Chad and Niger on the SCF website as a result of studies in that region over the last 10 years or so.

The respondents (n = 13) found it impossible to assess the current status, given the lack of recent information, but information collected via the internet regarding recent massacres of wildlife could enable a more reliable estimation to be made of the number of Dorcas gazelles that have been killed.

All respondents believed that the Dorcas gazelle is a threatened species (vulnerable or critically endangered), as are all other large ungulates (Barbary sheep, Ibex, etc.). Remnant populations are likely to disappear in a few years unless a combined political/military solution is found for the failing state of Libya.

All respondents believed that the overall protection of Dorcas gazelle could be increased through the education of locals throughout its range. They regarded human/livestock encroachment as a potential threat, although it appears at this point that the Dorcas gazelle may be capable of adapting to it. Some respondents (n = 5) also stated that the sale of gazelles in markets, either dead or alive (perhaps for the pet trade), is probably a drain on the wild population. They (n = 13) considered that poaching was definitely the main threat to the Dorcas gazelle and that this required conservation *ex situ* and wide-ranging awareness-raising campaigns. The respondents (n = 13) stated that possible solutions included recruiting personnel dedicated to conservation education. Such personnel need to be acceptable to the local people and have the means to stay on site for long periods. If local people value the Dorcas gazelle, then they will watch out for them.

Children who grow up with a conservation ethic are more likely to assist conservation efforts. Where possible, it also helps to structure protected areas so that they benefit the local people, including making jobs dependent on there being Dorcas gazelle in the area, providing schools for the children and programmes to allow people and wildlife to co-exist. The respondents argued that, if they are not completely eliminated, populations of Dorcas gazelle may build up quite quickly, but this would require anti-poaching controls to be in place.

4.3.1.4. Populations, threats and conservation measures concerning the Dorcas gazelle outside Libya

All respondents (n = 13) were aware that Dorcas gazelle are still found in North Africa, but they had no estimates and believed that herds were small. Some respondents (n = 7) had seen Dorcas gazelle in Niger and Chad, where they believed the numbers were quite good, especially in comparison to Dama gazelles and Addax. The respondents (n = 3) stated that there were Dorcas gazelle everywhere in the Sahara, but they were nearly extinct in the western desert of Egypt and that numbers in herds on the northern edge of the Sahara never exceed 10 nowadays (2015).

Legal protection is in place in all areas of the Dorcas gazelle's natural range in Tunisia, Morocco, Senegal, Chad, Algeria, Egypt and Sudan and hunting is illegal. However, poaching still occurs, sometimes with large numbers of animals being removed in a single incident. The respondents (n = 13) were aware of good examples of captive breeding sites in those countries but not of animals being released into natural sites.

Two respondents were also aware of one, or possibly two, private herds of Dorcas gazelle on Texas ranch lands in the USA since at least 1996. Each herd might have 6 to 12 individuals. All of these animals are confined by fences and none are loose in the wild.

All respondents (n = 13) stated that the main threats to Dorcas gazelle across their natural range are poaching from cars and the use of automatic rifles. Loss of habitat has also been a threat since the early 20th century and it is increasing with current poor security situations. Some (n = 7) argued that the habitat is still good in those countries, and the Dorcas gazelle is well-adapted to dealing with humans.

Some of the respondents (n = 3) also referred to illegal off-take by tourist hunters from the Gulf States, competition from pastoral expansion into previously uninhabited areas (n = 8), habitat conversion (n = 3) and habitat loss (n = 9). The impacts of all of these have increased significantly over the past 10 - 20 years.

Three respondents argued that protection on paper will not save the species and they were not aware of any specific conservation measures for Dorcas gazelle. They knew of a goal to restrict sites within some of the reserves to keep human/livestock habitation out of those areas but stated that this measure has not been enforced and currently wells can be installed wherever people want them.

Although the respondents (n = 13) referred to *ex situ* captive breeding programmes, they all considered that conservation is best conducted *in situ*, particularly in protected areas. Many protected areas have been created all over the range of the species. They (n = 13) argued that, when such programmes are inadequately funded, little is achieved. Hunting bans on foreign tourists have been positive (n = 3), as have high-level restrictions on military hunting (n = 11). In general, however they (n = 13) felt that protected areas are useful but too under-funded and under-staffed to be fully effective.

4.3.2. The perspectives of local stakeholders on aspects of Dorcas gazelle

A total of 130 questionnaires (100% response rate) were completed during the first phase of fieldwork in 2015 by respondents in the following categories: hunters or other individuals interested in hunting (57.7%), interested individuals who live near to where Dorcas gazelle are found (19.2%), and members of conservation organisations or other individuals interested in wildlife conservation (23.1%). The respondents ranged from 17 to >70 years, but most of the respondents were in the older age groups. Their level of education ranged from uneducated to postgraduate level (Table 4.3).

Table 4.3. Profile of respondents for the 2015 questionnaire cohort by age group and level of education (n = 130) (uneducated = did not attend school or attended school to age11, high school = attended school until age 17, university = studied to under-graduate or post-graduate degree level)

Age group/ years	Uneducated	High school	University	Total	Percentage (%)
17-40	4	5	30	39	30
41-60	7	34	32	73	56.2
61 to >70	1	3	14	18	13.8
Total	12	42	76	130	100
Percentage (%)	9.2	32.3	58.5	100	

The second questionnaire was administered in 2016 and a total of 100 questionnaires were completed. Again, the respondents ranged from 17 to >70 years of age. Their level of education ranged from uneducated to postgraduate (Table 4.4).

Table 4.4. Profile of respondents by age group and level of education (n = 100) for the 2016 questionnaire cohort

Age group/ years	Uneducated	High school	University	Total	Percentage (%)
17-40	0	5	33	38	38
41-60	4	23	30	57	57
61 to >70	1	1	3	5	5
Total	5	29	66	100	100
Percentage (%)	5	29	66	100	

The respondents belonged to the following categories: hunters or other individuals interested in hunting (55%), interested individuals who live near to where Dorcas gazelle are found (30%), and members of conservation organisations or other individuals interested in wildlife conservation (15%).

4.3.2.1. Current status and population trends

All respondents referred to the Dorcas gazelle as the Lareal gazelle, although 44.6% of them knew its scientific name. In the 2015 survey, 80.8% of respondents indicated that Dorcas gazelle live in the pre-Saharan, semi-desert region, while 19.2% of respondents stated that Dorcas gazelle live in desert areas. 39.2% of respondents had seen Dorcas gazelle in the wild during the previous 4 years (2011-15). However, in the 2016 survey, 47% of respondents reported having seen the gazelle in the wild during the previous year. The results of a T-test (Table 4.5) shows that there was no significant difference between the percentage of respondents who reported sightings of gazelle in 2011-5 and those reporting sightings in 2016 (Mean = -2.94, SD = 10.53, t = -624, P > 0.566), indicating that there is also no difference between the number of gazelles that were sighted in the two periods of study (2011-2015 and 2016). The difference in the percentages in the two periods may be due to the different sample sizes in the two periods.

Table 4.5. T-test analysis (Paired Samples Test) of the sighting of gazelle in the periods 2011-15 and 2016

Paired Differences	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence interval of Difference: Lower	95% Confidence interval of Difference: Upper			
2011-2015 and 2016	-2.94000	10.53603	4.71186	-16.02221	10.14221	-624	4	0.566

The locations and numbers of Dorcas gazelle sighted in the wild by respondents in the study area as reported in both surveys are shown in Fig. 4.1 and Table 4.6 (for more specific details, see Appendix 7). These locations are shown on the map in Fig. 4.2. The place names given are those used by the local population.

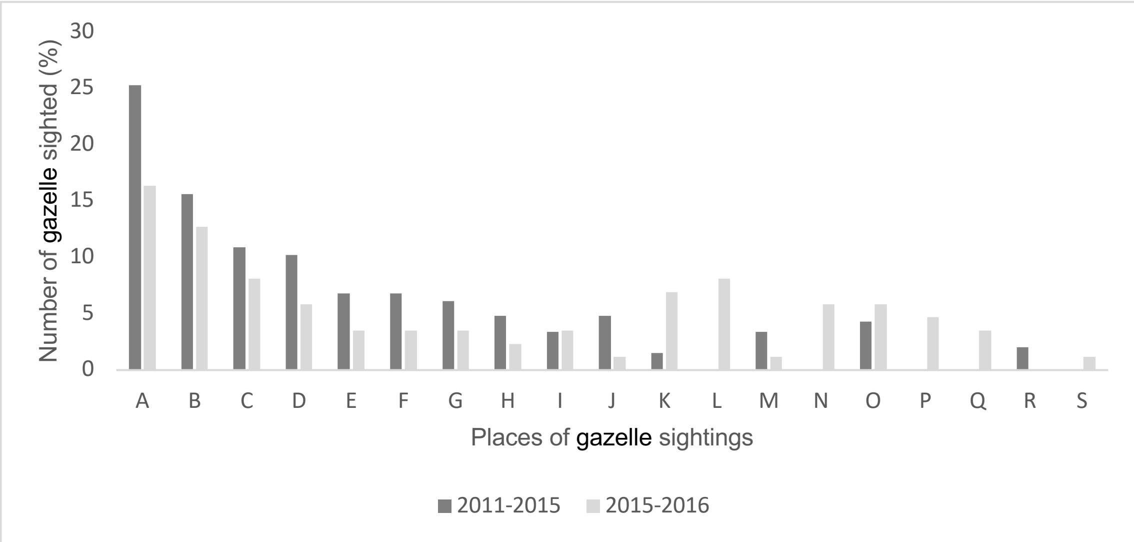


Fig. 4.1. Approximate locations and percentages of Dorgas gazelle sighted by respondents in the study area in both surveys 2011-2015 (n=130) and 2015-2016 (n=100). Key: A = Alkabar, B = Alhasena, C = Bosfia, D = South west Gardas, E = Thahar Hamala, F = South of Mrawah, G = Al Akaer- Akaer Alhaet, H = Alklaiat- Klaiat Noara, I = El Mekhili, J = Am Algazallan, K = Wadi Alsfa, L = South of Wadi Almahaga, M = Bulat Borkaes, N = Wadi Alsafak, O = Altheapan, P = Bulat Mahers, Q = Tanamlow, R = Masos and S = Bulat Alraml

Table 4.6. Overview of the locations of individual gazelle sightings in the wild in the study area by respondents from 2011 to 2016 (combined data from both surveys). For more specific details, see Appendix 7

Place names	No. of individual gazelles sighted	Percentage of total sightings	Average no. of sightings per respondent	No. of respondents (n = 230)	
				No	%
A. Alkabar (Aljasha)	51	21.9	2.8	18	7.8
B. Alhasena (Aljasha)	34	14.6	2.1	16	7
C. Bosfia (Aljasha)	23	9.9	2.9	8	3.5
D. South west Gardas (Aljasha)	20	8.5	2.2	9	3.9
E. Thahar Hamala (Aljasha)	13	5.6	2.6	5	2.2
F. South of Mrawah (Aljasha)	13	5.6	3.2	4	1.7
G. Al Akaer- Akaer Alhaet (Alsrwal)	12	5.1	2.4	5	2.2
H. Alklaiat- Klaiat Noara (south of Candula) (Aljasha)	9	3.9	3	3	1.3
I. El Mekhili (Alsrwal)	8	3.5	2.7	3	1.3
J. Am Algazallan (Alsrwal)	8	3.5	2.7	3	1.3
K. Wadi Alsfa (Aljasha)	8	3.5	2	4	1.7
L. South of Wadi Almahaga (Aljasha)	7	3.0	1.4	5	2.2
M. Bulat Borkaes (Albulat)	6	2.5	2	3	1.3
N. Wadi Alsafak (Aljasha)	5	2.1	1.7	3	1.3
O. Altheapan area (Alsrwal)	5	2.1	1.7	3	1.3
P. Bulat Mahers (Albulat)	4	1.7	2	2	0.9
Q. Tanamlow (Alsrwal)	3	1.3	1.5	2	0.9
R. Masos (Alsrwal)	3	1.3	3	1	0.4
S. Bulat Alraml (Albulat)	1	0.4	1	1	0.4
Total	~233	100	42.9	98	42.6

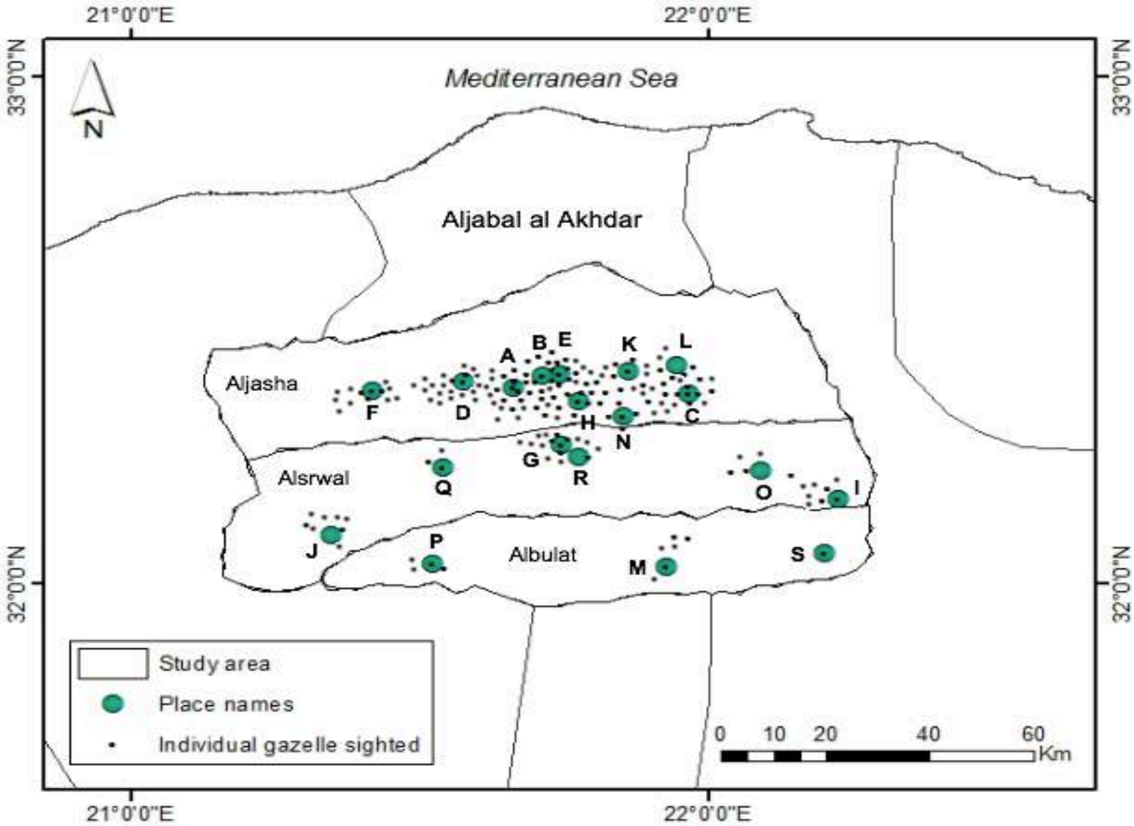


Fig. 4.2. Approximate locations of individual gazelles sighted by respondents in the study area from 2011 to 2016 (combined data from both surveys). Key: A = Alkabar, B = Alhasena, C = Bosfia, D = South west Gardas, E = Thahar Hamala, F = South of Mrawah, G = Al Akaer- Akaer Alhaet, H = Alklaiat- Klaiat Noara, I = El Mekhili, J = Am Algazallan, K = Wadi Alsfa, L = South of Wadi Almahaga, M = Bulat Borkaes, N = Wadi Alsafak, O = Altheapan, P = Bulat Mahers, Q = Tanamlow, R = Masos and S = Bulat Alraml

Most sightings of Dorcas gazelle in the study area were around Alkabar (21.9%) and Alhasena (14.6%), as shown in Fig. 4.3. The sizes of groups of gazelle sighted in the study area were very small as shown in Table 4.7.

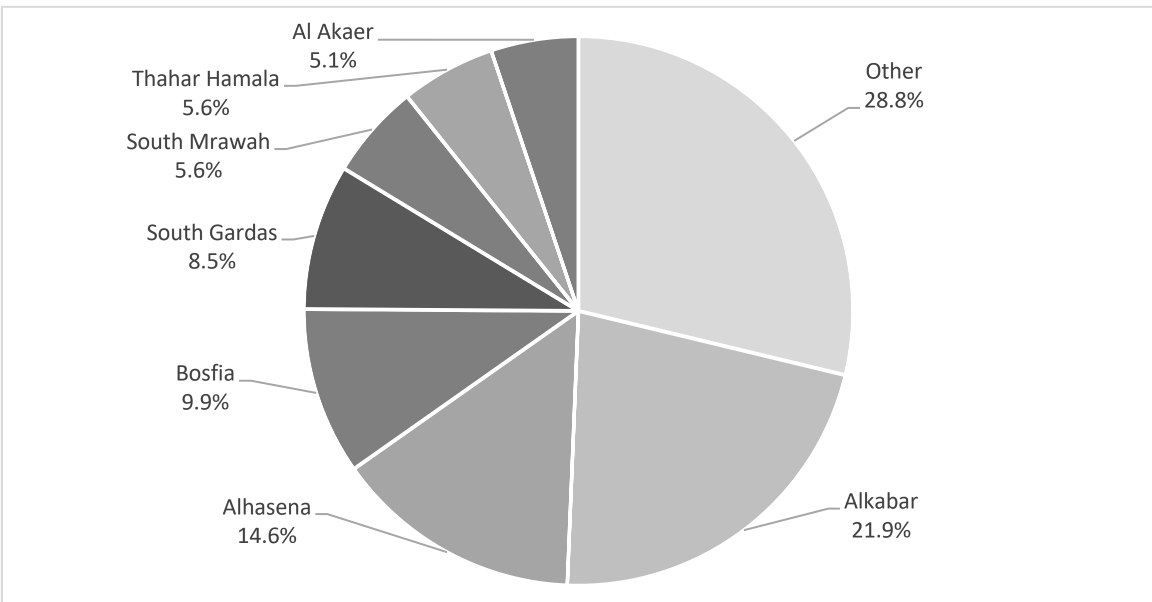


Fig. 4.3. Percentage of Dorcas gazelle sightings by place (combined data from both surveys)

Table 4.7. Estimates of gazelle group sizes as reported by respondents' (%) during the last 5 years (2011 - 2016)

Year	Gazelle group size estimates (%) during the last 5 years (2011-2016)						
	1	2	3	4 - 5	Small herds	Large herds	None seen
2011-2015	5.4	5.4	19.2	6.9	2.3	0	60.8
2016	17	21	9	0	0	0	53

4.3.2.2. The relationship between gazelle sightings and the variables

The relationships between gazelle sightings and age, education level and category of respondent were analysed using chi-square and systematic measures to identify if there were any statistical significances. The relationship with age showed no statistical significance, but level of education and category of respondent both proved to be statistically significant in both survey years.

In 2015, the highest proportion of sightings (58.3%) was made by respondents defining themselves as uneducated. A cross-tabulation of gazelle sightings and level of education is presented in Table 4.8. The chi-square test showed a statistically significant relationship: X^2 (1, N-130) = 6.444, $p = 0.040$, therefore $p < 0.05$ (Table 4.9).

Table 4.8. Responses to the question 'Have you ever seen Dorcas gazelle in the wild during the previous 4 years (2011 - 2015)?' according to educational level (Expected values derived from SPSS)

Education level	Frequency	Have you ever seen Dorcas gazelle in the wild during the last 4 years?		Total
		Yes	No	
Uneducated	Count	7	5	12
	Expected count	4.7	7.3	12
	% within education level	58.3	41.7	100
High school	Count	21	21	42
	Expected count	16.5	25.5	42
	% within education level	50	50	100
University	Count	23	53	76
	Expected count	29.8	46.2	76
	% within education level	30.3	69.7	100
Total	Count	51	79	130
	% within education level	39.2	60.8	100

Table 4.9. Chi-Square to test the relationship between gazelle sightings and education level. (df is degrees of freedom)

	Value		df		Asymptotic. Significance. (2-sided)	
	2015	2016	2015	2016	2015	2016
Pearson Chi-Square	6.444[a]	11.552[a]	2	2	.040	.003
Likelihood Ration	6.427	11.789	2	2	.040	.003
Linear-by-Linear Association	6.112	9.344	1	1	.013	.002
No. of Valid Cases	130	100	-	-	-	-

a. 1 cells (16.7%) has an expected count less than 5. The minimum expected count is 4.71 for 2011 and 2.82 for 2016

In 2016, the highest proportion of sightings (71.4%) was made by respondents defining themselves as educated to high school level as can be seen in the cross-tabulation of gazelle sightings and level of education in Table 4.10. The chi-square test shows a strong statistically significant relationship: X^2 (1, N-100) = 11.552, p = 0.003 (Table 4.9).

Table 4.10. Responses to the question 'Have you ever seen Dorcas gazelle in the wild during the last year (2016)' according to education level (Expected values derived from SPSS)

Education level	Frequency	Have you ever seen gazelle in the wild during the last year (2016)?		Total
		Yes	No	
Uneducated	Count	4	2	6
	Expected count	2.8	3.2	6.0
	% within education level	66.7	33.3	100
High school	Count	20	8	28
	Expected count	13.2	14.8	28
	% within education level	71.4	28.6	100
University	Count	23	43	66
	Expected count	31	35	66
	% within education level	34.8	65.2	100
Total	Count	47	53	100
	% within education level	47	53	100

In both survey years, the highest proportion of respondents who reported gazelle sightings were hunters (54.7% in 2015 and 61.8% in 2016). A cross-tabulation of gazelle sightings and category of respondents is contained in Table 4.11 for the first survey and in Table 4.12 for the second survey year. The result of the chi-square test shows a highly statistically significant relationship with this variable in both years. In 2015, the significance was X^2 (1, N-130) = 26.869, p = 0.001. In 2016, the significance was X^2 (1, N-100) = 18.312, p = 0.001 (Table 4.13).

Table 4.11. Category of respondents for the question 'Have you ever seen Dorcas gazelle in the wild during the previous 4 years (2011 - 2015)?' (Expected values derived from SPSS)

Category	Frequency	Have you ever seen Dorcas gazelle in the wild during the last 4 years?		Total
		Yes	No	
Hunter	Count	41	34	75
	Expected count	29.4	45.6	75
	% within category	54.7	45.3	100
Local inhabitant	Count	10	15	25
	Expected count	9.8	15.2	25
	% within category	40	60	100
Member of a conservation organisation	Count	0	30	30
	Expected count	11.8	18.2	30
	% within category	0	100	100
Total	Count	51	79	130
	% within category	39.2	60.8	100

Table 4.12. Categories of respondents for the question 'Have you ever seen Dorcas gazelle in the wild during the last year (2016)'? (Expected values derived from SPSS)

Category	Frequency	Have you ever seen Dorcas gazelle in the wild during the last year (2016)?		Total
		Yes	No	
Hunter	Count	34	21	55
	Expected count	25.9	29.2	55
	% within category	61.8	38.2	100
Local inhabitant	Count	13	17	30
	Expected count	14.1	15.9	30
	% within category	43.3	56.7	100
Member of a conservation organisation	Count	0	15	15
	Expected count	7.1	8	15
	% within category	0	100	100
Total	Count	47	53	100
	% within category	47	54	100

Table 4.13. Chi-Square to test the relationship between gazelle sightings with category of respondent. (df is degrees of freedom)

	Value		df		Asymptotic. Significance. (2-sided)	
	2015	2016	2015	2016	2015	2016
Pearson Chi-Square	26.869[a]	18.312[a]	2	2	.001	.001
Likelihood Ration	37.172	24.071	2	2	.000	.000
Linear-by-Linear Association	25.370	17.004	1	1	.000	.000
No. of Valid Cases	130	100	-	-	-	-

a. 0 cells (0.0%) have an expected count less than 5. The minimum expected count is 9.81 for 2011 and 7.05 for 2016

4.3.2.3. Relationship between estimates of the decrease in Dorcas gazelle numbers and the variables

100% of respondents of both questionnaires (2015 and 2016) confirmed that the Dorcas gazelle had decreased in the study area for the 2015 survey in the period between 2011 - 2015 and for the 2016 survey in the previous year. The majority of respondents (79.3% from 2015 and 75% from 2016) estimated the decline to be in the range 81% and 100% respectively (Fig. 4.4).

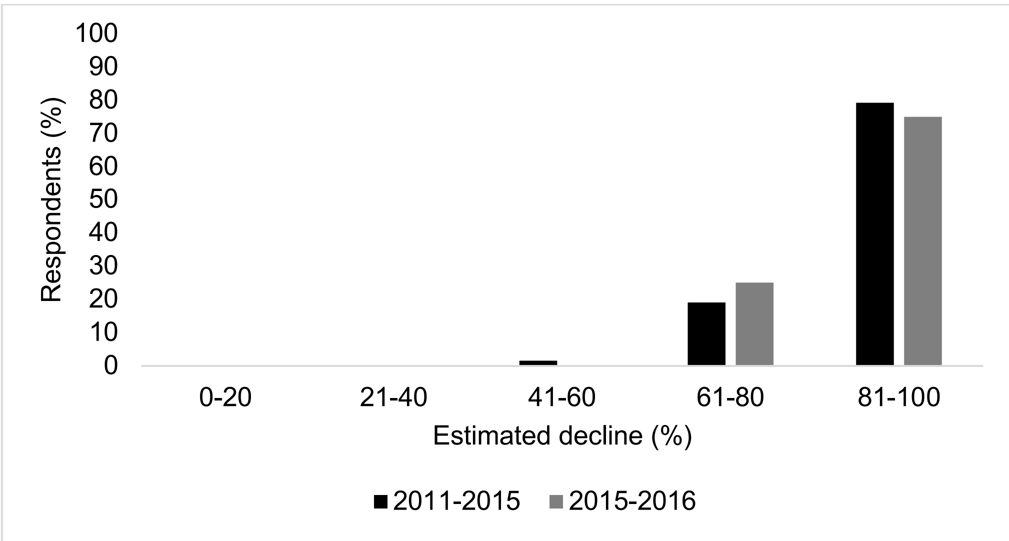


Fig. 4.4. The decline of Dorcas gazelle during the period 2011 - 2016 as estimated by respondents

The relationships between estimates of the decrease in the number of Dorcas gazelle and the variables age, education level and category of respondent were analysed and only the relationship with age showed a statistical significance and only in 2015. In the 2015 survey, the majority of respondents (79.3%) estimated a decline in Dorcas gazelle numbers to be in the range 81% and 100% over 5 years. The highest proportion who estimated this level of decrease (92.3%) was in the age group 17 - 40 years. Table 4.14 contains a cross-tabulation of the relationship between estimates of the decrease in Dorcas gazelle numbers and age groups. The chi-square test showed there was a statistically significant relationship with this variable in 2015: X^2 (1, N-130) = 12.339, p = 0.015 (Table 4.15). However, no significant relationship with age was found in 2016.

Table 4.14. Estimates of the decrease of Dorcas gazelle numbers in the wild during the previous 4 years (2011 - 2015) according to age group (Expected values derived from SPSS)

Age group (years)	Frequency	What is your estimate of the decrease of Dorcas gazelle numbers during the last 4 years in areas where the gazelle has lived recently?			Total
		41-60%	61-80%	81-100%	
17- 40	Count	0	3	36	39
	Expected count	0.6	7.5	30.9	39
	% within age group	0	7.7	92.3	100
41- 60	Count	2	14	57	73
	Expected count	1.1	14	57.8	73
	% within age group	2.7	19.2	78.1	100
61 to >70	Count	0	8	10	18
	Expected count	0.3	3.5	14.3	18
	% within age group	0	44.4	55.6	100
Total	Count	2	25	103	130
	% within age group	1.5	19.2	79.2	100

Table 4.15. Chi-Square to test the relationship between an estimate of the decrease in Dorcas gazelle numbers and age group. (df is degrees of freedom)

	Value	df	Asymptotic. Significance. (2-sided)
Pearson Chi-Square	12.339[a]	4	.015
Likelihood Ration	12.372	4	.015
Linear-by-Linear Association	8.507	1	.004
No. of Valid Cases	130		-

a. 4 cells (24.4%) have an expected count less than 5. The minimum expected count is .28

4.3.2.4. Attitudes to hunting and reasons for the decrease in gazelle numbers

Respondents who reported that gazelle numbers had decreased in the study area were asked if they thought that the conflict in Libya had led to increased pressures on wildlife and particularly on the Dorcas gazelle (open question no. 7). The respondents all agreed that the Libyan conflict in 2011 had increased the pressure on wildlife, resulting in a decrease in numbers of Dorcas gazelle, because of the absence of security and the large number and more widespread availability of war weapons. This had resulted in overhunting which had increased rapidly during the 4 - 5 years preceding the survey. However, the respondents, irrespective of age, education level and category, stated that the conflict was only one of a number of factors that had led to a decline in wildlife, and that there had been a noticeable decline in populations over the preceding 10 years. Their responses helped to define the main threats to the population before and after the conflict in Libya 2011 (Fig. 4.5).

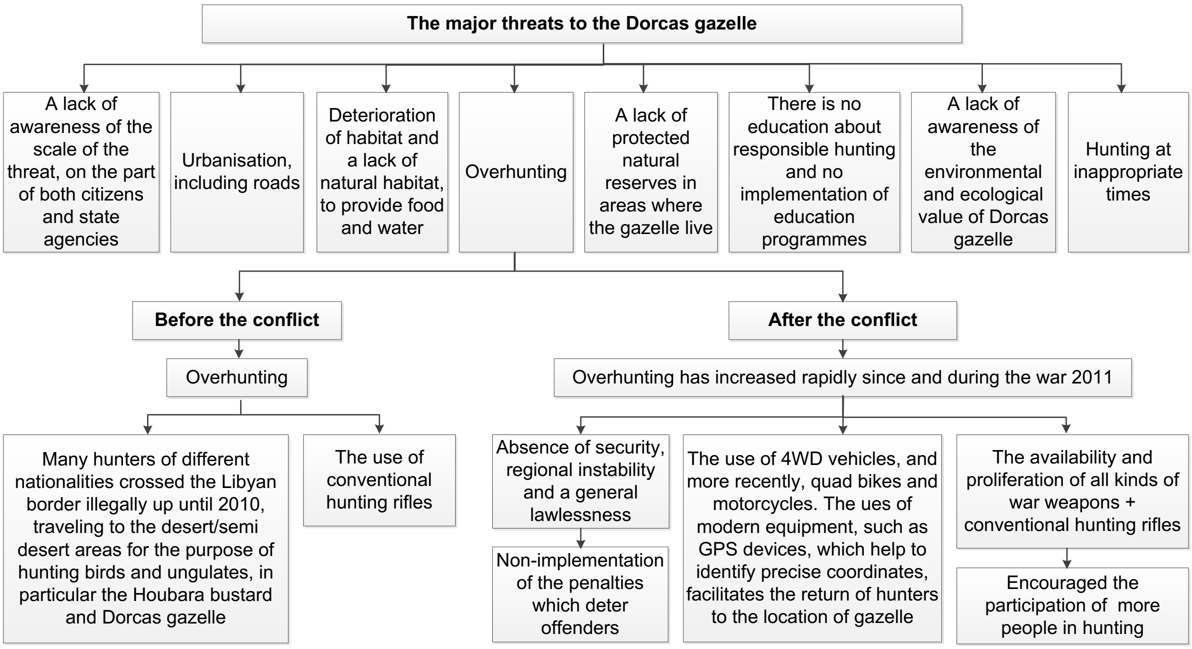


Fig. 4.5. Opinions of respondents about threats and the factors that led to the decline of wildlife, including the Dorcas gazelle population, before and after the conflict in Libya which began in 2011 (answers to open question no. 7)

Table 4.16 shows the responses to the 15 statements given in question 8, with mean score calculated for the responses from 1 (strongly disagree) to 5 (strongly agree). 97% of the respondents strongly disagreed, or disagreed, that there are too many gazelles in the study area (mean Likert score 1.324).

All the respondents (to open question no. 7 and closed question 8) strongly agreed or agreed, that the Libyan conflict in 2011 and regional instability had increased the pressure on wildlife, including the decrease in numbers of Dorcas gazelle (mean Likert score 4.882). Local respondents believed that the most probable reason for the decline was overhunting, with 100% of the respondents strongly agreeing, or agreeing, that overhunting led to low numbers and the decrease of Dorcas gazelle (mean Likert score 4.882). Furthermore, 98.5% of respondents strongly agreed, or agreed, that a lot of gazelle were killed by hunters (mean Likert score 4.773).

Additionally, 91.5% of respondents strongly disagreed, or disagreed, that many gazelles were killed by wild predators (mean Likert score 1.356). The majority of respondents (76.1%) confirmed that there were not many wild predators in the study area (mean Likert score 2.244). In terms of other animals, 71.6% of respondents strongly agreed, or agreed, that there were too many livestock and camels in the study area (mean Likert score 4.322).

96.9% of respondents strongly agreed, or agreed, that the acquisition of hunting tools and modern means of transportation had led to low numbers and the decrease of Dorcas gazelle with a mean Likert score of 4.798.

For the statement ‘hunting at inappropriate times has led to low numbers of Dorcas gazelle’, 92.3% of respondents strongly agreed, or agreed, that hunting in the mating season and breeding season had led to low numbers of gazelles (mean Likert score 4.747). Also, the respondents considered that there was a lack of environmental awareness and a lack of community education in the local communities. The results indicate that 95.4% of respondents strongly agreed, or agreed, that a lack of environmental awareness of the value of gazelle has led to low numbers and decrease of this gazelle (mean Likert score 4.640). The respondents strongly agreed (98.5%), or agreed, that communities and hunters, needed more information and awareness about the value of the gazelle with a mean Likert score of 4.813.

The respondents believed that another factor leading to a decline in gazelle numbers was habitat loss due to the continuing development and urbanisation of the region south of the Green Mountain area. 39.3% of respondents agreed, or were neutral, whereas 60.7% strongly disagreed, or disagreed, with the statement that urbanisation had led to low numbers of gazelle (mean Likert score 2.622). Furthermore, 70.8% of respondents agreed, or strongly agreed, that a lack of natural habitat to provide food and water had led to low numbers and the decrease of Dorcas gazelle (mean Likert score 3.662).

The results show that 63.9% of the respondents disagreed, or strongly disagreed, that the people in the study area needed to eat bush meat (mean Likert score 2.420). All respondents agreed that more research and monitoring were needed on gazelle with a mean Likert score of 4.864.

Table 4.16. Respondents' opinions about the relative importance of issues affecting Dorcas gazelle and all wildlife in the study area. Question 8, (n = 130)

	Issues or opinions	Strongly disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly agree (%)	Mean Likert score
1.	There are too many gazelle	70.8	26.2	2.2	0.8	0	1.324
2.	The recent war in Libya (in 2011) has led to low numbers and the decrease of Dorcas gazelle	0	0	0	10	90	4.882
3.	Overhunting has led to low numbers and the decrease of Dorcas gazelle	0	0	0	8.5	91.5	4.882
4.	A lot of gazelle are killed by hunters	1.5	0	0	14.6	83.9	4.773
5.	A lot of gazelle are killed by wild predators	73	18.5	6	2.5	0	1.356
6.	There are too many wild predators	16.1	60	12.3	10.8	0.8	2.244
7.	There are too many livestock	0	3.8	24.6	15.5	56.1	4.322
8.	Acquisition of hunting tools and modern means of transportation led to low numbers and the decrease of Dorcas gazelle	0	0	3.1	11.5	85.4	4.798
9.	Hunting at inappropriate times (e.g. mating season) has led to low numbers and the decrease of Dorcas gazelle	0	0	7.7	12.3	80	4.747
10.	A lack of environmental awareness of the value of Dorcas gazelle has led to low numbers and the decrease of this gazelle	0.8	1.5	2.3	16.9	78.5	4.640
11.	Communities and hunters need more information and awareness of the value of the gazelle	0	1.5	0	13.1	85.4	4.813
12.	Urbanization, including roads has led to low numbers and the decrease of Dorcas gazelle	3	57.7	20.8	8.5	10	2.622
13.	A lack of natural habitat, to provide food and water have led to low numbers and the decrease of Dorcas gazelle	1.5	6.9	20.8	62.3	8.5	3.662
14.	People in this area are hungry and therefore need to eat bush meat	16.9	47.7	16.9	18.5	0	2.420
15.	More research and monitoring are needed on the gazelle	0	0	0	10.8	89.2	4.864

It is clear that some factors leading to a decrease in the number of Dorcas gazelle arose after the 2011 conflict in Libya as a result of the lack of security and an absence of government. This resulted in an increase in assaults on and killings of gazelle. The responses are summarised in Fig 4.5 and Table 4.16. The eleven most significant threats to the Dorcas gazelle in the study area were extrapolated and then prioritised according to the mean scores of the responses from 1 (strongly disagree) to 5 (strongly agree), as shown in Fig. 4.6.

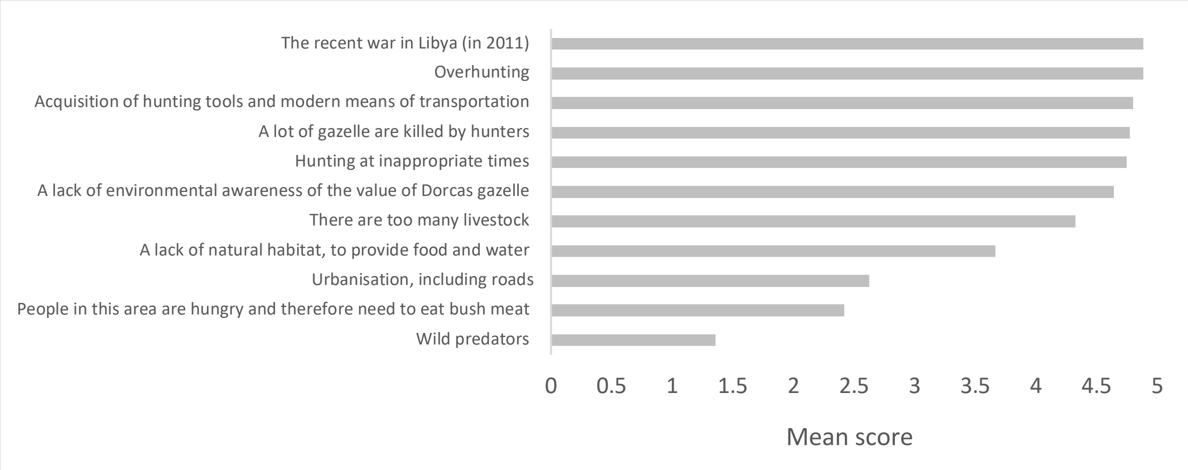


Fig. 4.6. Prioritisation of threats to the Dorcas gazelle in the study area according to the mean scores of the responses

4.3.2.5. Assaults and gazelle killed

20.8% of all respondents of the 2015 questionnaire reported specific assaults that had occurred which led to the killing of Dorcas and other gazelle in Libya. 3.0% of all respondents reported that assaults had occurred in 2016 which had also led to the killing of Dorcas gazelle in the study area. These attacks are shown in Table 4.17 with the approximate locations of the more recent attacks shown in Fig. 4.7.

Table 4.17. Attacks on gazelle known to the respondents that had occurred at different locations in Libya (Fig. 4.7) as reported during both surveys

Incident	Species	Date of attack	Location (codes as shown in Fig. 4.7)	Method Used	Number of gazelle killed	Reasons
1	Dorcas gazelle	2016	Bosfia- Aljasha area (C)	4×4 Vehicle + Shotgun (cartouche)	1	Hobby and Enjoyment
2	Dorcas gazelle	2016	Thahar Hamala- Aljasha area (E)	4×4 Vehicle + Shotgun (cartouche)	3	Hobby and Enjoyment
3	Dorcas gazelle	2016	Wadi Alsafak- Aljasha area (N)	4×4 Vehicle + Shotgun (cartouche)	1	Hobby and Enjoyment
4	Dorcas gazelle	2015	Akakus Mountains (Ghat - South West Libya)	4×4 Vehicle + Kalashnikov gun and PKT machinegun	45	Hobby and Enjoyment
5	Dorcas gazelle	2014	Ber Atshan (South Hamaha Al Hamra- Western Libya)	4×4 Vehicle + Kalashnikov gun and PKT machinegun	25	Hobby and Enjoyment
6	Dorcas gazelle	2013	West of Libya	4×4 Vehicle + war weapons	20	Hobby and Enjoyment
7	Dorcas gazelle	2013	Alkabar- Aljasha area (A)	4×4 Vehicle + Shotgun (cartouche)	11	Hobby and Enjoyment
8	Dorcas gazelle	2012	Bosfia- Aljasha area (C)	4×4 Vehicle + Shotgun (cartouche)	2	Hobby and Enjoyment
9	Dorcas gazelle	2012	South of the Green Mountain- Aljasha area (F)	4×4 Vehicle + Shotgun (cartouche)	31	Hobby and Enjoyment

10	Dorcas gazelle	2011	Jabal Uweinat (South East Libya)	4×4 Vehicle + Kalashnikov gun	13	Hobby and Enjoyment
11	Dorcas gazelle	2010	South of Wadi Almahaga (D)	4×4 Vehicle + Shotgun (cartouche)	1	Hobby and Enjoyment
12	Dorcas gazelle	2008	El Haruj El Aswad (Centre of Libya)	4×4 Vehicle + Shotgun (cartouche)	3	Hobby and Enjoyment
13	Dorcas gazelle	2003	South of the Green Mountain- Aljasha area (F)	4×4 Vehicle + Shotgun (cartouche)	5	Hobby and Enjoyment
14	Dorcas gazelle	2002	West of El Mekhili (I)	4×4 Vehicle + Shotgun (cartouche)	7	Hobby and Enjoyment
15	Slender horned gazelle	2000	Al Akaer- Aljasha area (G)	4×4 Vehicle + Shotgun (cartouche)	5	Hobby and Enjoyment
16	Dorcas gazelle	1999	Wadi Alsafak- Aljasha area (N)	4×4 Vehicle + Shotgun (cartouche)	6	Hobby and Enjoyment
17	Dorcas gazelle	1995	South of the Green Mountain- Aljasha area (F)	4×4 Vehicle + Shotgun (cartouche)	7	Hobby and Enjoyment
18	Dorcas gazelle	1995	West of El Mekhili (I)	4×4 Vehicle + Shotgun (cartouche)	9	Hobby and Enjoyment
19	Dorcas gazelle	1995	El Haruj El Aswad (Centre of Libya)	4×4 Vehicle + Shotgun (cartouche)	5	Hobby and Enjoyment
20	Dorcas gazelle	1995	Jabal Uweinat (South East Libya)	4×4 Vehicle + Shotgun (cartouche)	2	Hobby and Enjoyment
21	Dorcas gazelle	1993	Al Akaer- Alsrwal area (G)	4×4 Vehicle + Shotgun (cartouche)	2	Hobby and Enjoyment
22	Dorcas gazelle	1992	Bulat Borkaes (M)	4×4 Vehicle + Shotgun (cartouche)	1	Hobby and Enjoyment
23	Dorcas gazelle	1992	Al Akaer- Alsrwal area (G)	4×4 Vehicle + Shotgun (cartouche)	1	Hobby and Enjoyment
24	Dorcas gazelle	1991	Al Akaer- Alsrwal area (G)	4×4 Vehicle + Shotgun (cartouche)	3	Hobby and Enjoyment
25	Dorcas gazelle	1991	Hesht Msdnaha - Aljasha area (H)	4×4 Vehicle + Shotgun (cartouche)	2	Hobby and Enjoyment
26	Dorcas gazelle	1990	Bulat Mahers (P)	4×4 Vehicle + Shotgun (cartouche)	3	Hobby and Enjoyment
27	Dorcas gazelle	1988	Bulat Borkaes (M)	4×4 Vehicle + Shotgun (cartouche)	50	Hobby and Enjoyment
28	Dorcas gazelle	1986	Alkhsor- Aljasha area (B)	4×4 Vehicle + Shotgun (cartouche)	9	Hobby and Enjoyment
29	Dama gazelle (*Nanger dama*)	1978	South of the Green Mountain- Aljasha area (F)	4×4 Vehicle + Shotgun (cartouche)	19	Hobby and Enjoyment
30	Dorcas gazelle	1964	South of Suluq (North East Libya)	4×4 Vehicle + Shotgun (cartouche)	80	Hobby and Enjoyment

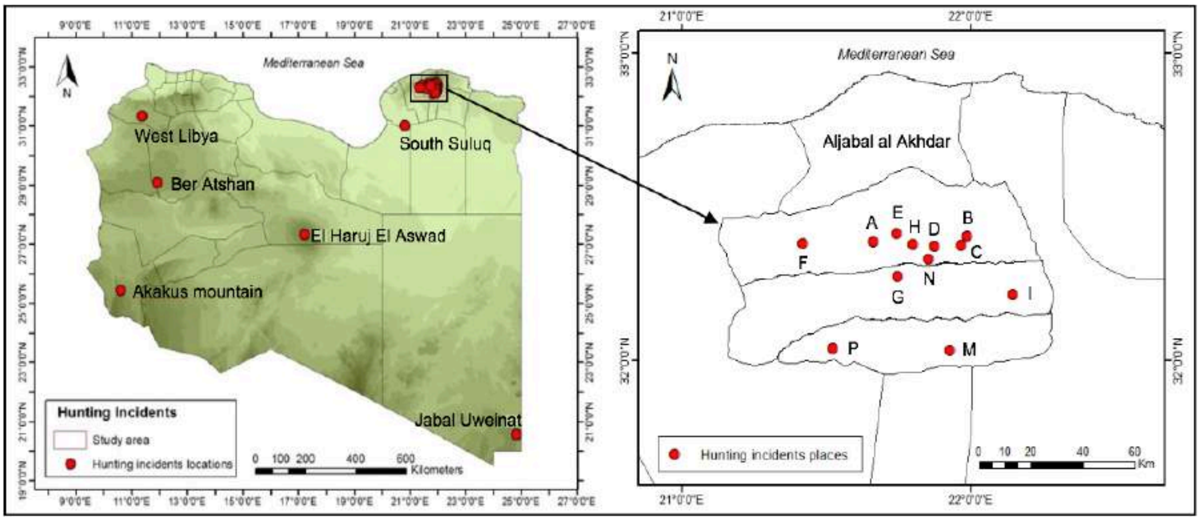


Fig. 4.7. Approximate locations of reported hunting incidents resulting in the killing of Dorcas gazelle or other species between 1964 and 2016 in Libya as a whole and in the study area. Key: A = Alkabar, B = Alkhsor, C = Bosfia**,** D = South of Wadi Almahaga, E = Thahar Hamala**,** F = South of Green Mountain**,** G = Al Akaer, H = Hesht msdnaha I = West of El Mekhili**,** M = Bulat Borkaes**,** N = Wadi Alsafak and P = Bulat Mahers

Figure. 4.8 shows the data from respondents relating to the number of assaults that resulted in the death of gazelle in Libya over the period 1964 - 2016. It can be clearly seen that there was an increase in the number of killings of gazelle during the conflict period which may be attributed to the factors identified in the Fig. 4.6. This led to an overall decrease in the number of gazelle.

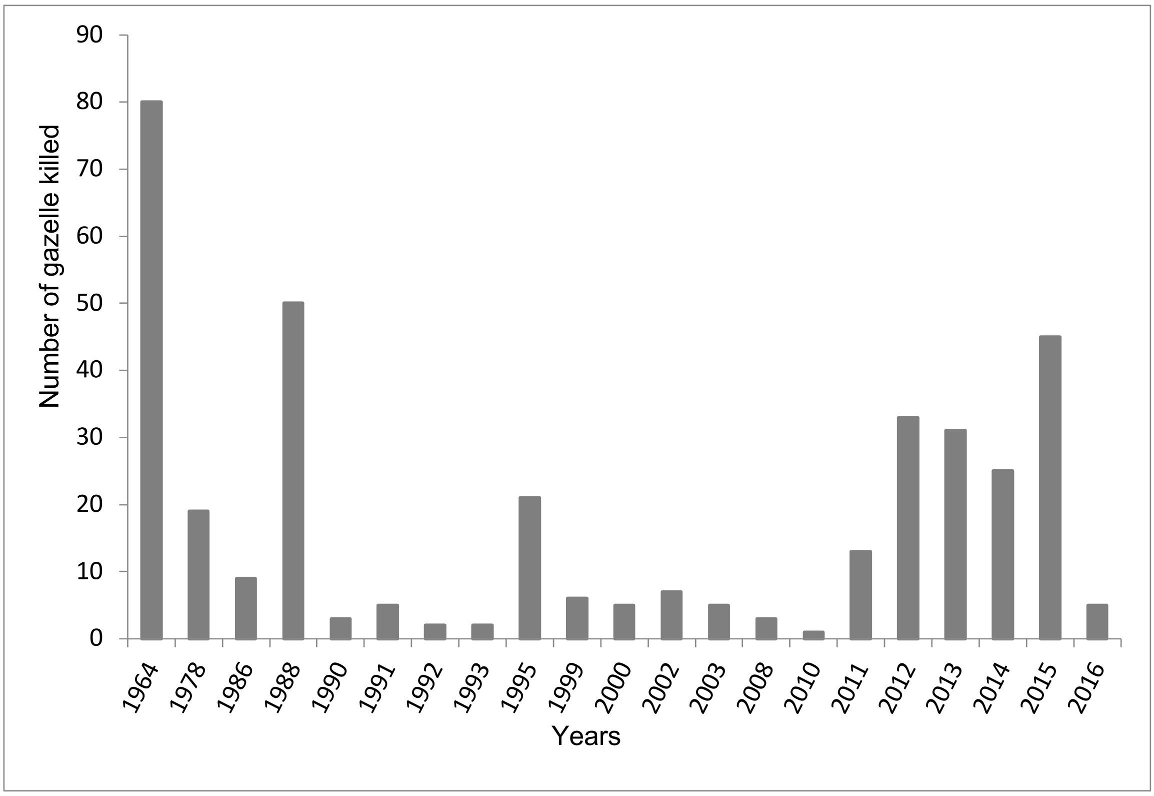


Fig. 4.8. Dorcas gazelle killings in Libya (including the study area) between 1964 and 2016 as reported by respondents

4.3.2.6. Relationship between reports of assaults on gazelle and the variables

The relationships between reports of assaults on Dorcas gazelle and the variables age, education level and category of respondent were analysed using chi-square and systematic measures to identify if there was any statistical significance. The relationship with level of education showed a statistical significance in both survey years. The majority of respondents who reported assaults on gazelle defined themselves as uneducated (50% in both survey years). A cross-tabulation of gazelle assaults and education level is given in Table 4.18 for the period 2011 - 2015 and in Table 4.19 for 2016. In 2015, the chi-square test (Table 4.20) showed a significant relationship: X^2 (1, N-130) = 6.915, p = 0.032.

In 2016, the chi-square test showed there was a highly statistically significant relationship between knowledge of assaults and education level: X^2 (1, N-100) = 48.454, p = 0.001 (Table 4.20).

Table 4.18. Knowledge of gazelle assaults (2015 survey) according to education level (Expected values derived from SPSS)

Education level	Frequency	Have you known of any incidents in the past when Dorcas gazelle or other gazelle species have been killed in Libya?		Total
		Yes	No	
Uneducated	Count	6	6	12
	Expected count	2.5	9.5	12
	% within education level	50	50	100
High school	Count	7	35	42
	Expected count	8.7	33.3	42
	% within education level	16.7	83.3	100
University	Count	14	62	76
	Expected count	15.8	60.2	76
	% within education level	18.4	81.6	100
Total	Count	27	103	130
	% within education level	20.8	79.2	100

Table 4.19. Knowledge of gazelle assaults (2016 survey) according to education level (Expected values derived from SPSS)

Education level	Frequency	Have you seen any incidents in the last year (since August 2015) when Dorcas gazelle or other gazelle species have been killed in Libya?		Total
		Yes	No	
Uneducated	Count	3	3	6
	Expected count	.2	5.8	6
	% within education level	50	50	100
High school	Count	0	28	28
	Expected count	.8	27.2	28
	% within education level	0	100	100
University	Count	0	66	66
	Expected count	2	64	66
	% within education level	0	100	100
Total	Count	3	97	100
	% within education level	3	97	100

Table 4.20. Chi-Square to test the relationship between gazelle assaults and education level. (df is degrees of freedom)

	Value		df		Asymptotic. Significance. (2-sided)	
	2015	2016	2015	2016	2015	2016
Pearson Chi-Square	6.915[a]	48.454[a]	2	2	.032	.001
Likelihood Ration	5.734	18.631	2	2	.057	.000
Linear-by-Linear Association	2.990	21.773	1	1	.084	.000
No. of Valid Cases	130	100	-	-	-	-

a. 1 cell (16.7%) has an expected count less than 5. The minimum expected count is 2.49 for 2011 and 0.18 for 2016

With regard to category of respondent, the highest proportion (36%) who reported knowledge of assaults on gazelle were hunters. The category of respondent showed a statistically significant relationship in 2015 only. Table 4.21 contains a cross-tabulation of the relationship between knowledge of gazelle assaults and the background of the respondents for the period 2011 - 2015. The chi-square test (Table 4.22) showed there is a highly statistically significant relationship with this variable: X^2 (1, N-130) = 24.990, p = 0.001.

Table 4.21. Knowledge of gazelle assaults (2011 - 2015) according to category of respondents (Expected values derived from SPSS)

Category	Frequency	Do you have knowledge of any incidents in the past when Dorcas gazelle or other gazelle species have been killed in Libya?		Total
		Yes	No	
Hunter	Count	27	48	75
	Expected count	15.6	59.4	75
	% within category	36	64	100
Local inhabitant	Count	0	25	25
	Expected count	5.2	19.8	25
	% within category	0	100	100
Member of a conservation organisation	Count	0	30	30
	Expected count	6.2	23.8	30
	% within category	0	100	100
Total	Count	27	103	130
	% within category	20.8	79.2	100

Table 4.22. Chi-Square to test the relationship between gazelle assaults and category of respondent (2011 – 2015). (df is degrees of freedom)

	Value	df	Asymptotic. Significance. (2-sided)
Pearson Chi-Square	24.990[a]	2	.001
Likelihood Ration	34.817	2	.000
Linear-by-Linear Association	21.017	1	.000
No. of Valid Cases	130	-	-

a. 0 cells (0.0%) have an expected count less than 5. The minimum expected count is 5.19.

In 2016, the only category of respondents who reported knowledge of assaults on gazelle was hunters. However, the figure was not statistically significant.

4.3.2.7. Occurrence of gazelle with other animal species and preferred vegetation species (2015 survey)

83.8% of respondents confirmed that, in the study area, Dorcas gazelle inhabit areas along with other species, especially with camels (*Camelus dromedarius*) and Houbara bustards (*Chlamydotis undulata*) (Table 4.23). They were also asked about the vegetation which the gazelle favour and all respondents indicated preferences were shown for the following shrubs: *Capparis spinosa*, *Rhamnus tripartita*, *Suaeda mollis*, *Matthiola longipetala, Didymus bipinnatus* and *Anabasis articulata*. The full results are shown in Table 4.24.

Table 4.23. The occurrence of Dorcas gazelle in association with other animal species. However, 30% of the respondents had no information regarding the association of Dorcas gazelle with other animal species (2015 survey)

Associated animal species	Respondents (n = 130)	
	No.	%
Camels (*Camelus dromedarius*)	91	70
Houbara bustards (*Chlamydotis undulata*)	91	70

Table 4.24. Preferred vegetation of the Dorcas gazelle in the study area (2015 survey)

Preferred vegetation		Category	Respondents (n = 130)	
Local name	Scientific name		No.	%
Kabbar	*Capparis spinosa*	Shrub	130	100
Halab	*Periploca angustifolia*	Shrub	87	66.9
Kazah	*Pituranthos tortuosus*	Shrub	95	73.1
Khrtab	*Polygonum equisetiforme*	Shrub	47	36.2
Methnan	*Thymelaea hirsute*	Shrub	107	82.3
Cedar	*Ziziphus lotus*	Shrub	55	42.3
Zater	*Thymus capitatus*	Shrub	23	17.7
Sheah	*Artemisia herba-alba*	Shrub	73	56.2
Salof	*Rhamnus tripartita*	Shrub	130	100
Ratem	*Retama raetam*	Shrub	96	73.8
Rameth	*Suaeda mollis*	Shrub	130	100
Shkarh	*Matthiola longipetala*	Shrub	130	100
Gdare	*Rhus triparti*	Shrub	31	23.8
Kataf	*Atriplex rosea*	Shrub	27	20.8
Lsls	*Didymus bipinnatus*	Shrub	130	100
Agram	*Anabasis articulata*	Shrub	130	100

4.3.2.8. Effectiveness of current and future conservation measures for Dorcas gazelle (questionnaire 2015)

Table 4.25 shows the opinions of the respondents on the effectiveness of conservation measures for Dorcas gazelle that could be used in the area south of Green Mountain at the time of the survey. There was strong agreement on a number of conservation measures but there was less support for ‘zoos’.

Table 4.25. Opinions of respondents regarding which conservation measures that could be used at the present time would be effective for the conservation of the Dorcas gazelle in the study area

Conservation measure	Strongly disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly agree (%)	Mean Likert score
Protection laws	0	0	0	13.8	86.2	4.839
Education of all members of the community of the importance of wildlife	0	0	0.8	16.1	83.1	4.825
Protected areas (nature reserves)	0	0.8	0	15.4	83.8	4.795
Captive breeding and reproduction of the gazelle	3	0.8	0.8	10.8	84.6	4.794
Zoos	0.8	0.8	4.6	16.9	76.9	4.739

Figure 4.9 shows the mean score results of the opinions of respondents about the effectiveness of potential conservation measures for Dorcas gazelle that could have been used at the time of the survey in the study area. The results (Figure 4.9) indicate that there was strong agreement about the effectiveness of protection laws, with a mean score of 4.839, followed by the necessity for education of all members of the community on the importance of wildlife (mean 4.825), then the establishment of protected areas (nature reserves) with a mean of 4.795 and the captive breeding and reproduction of the gazelle (mean of 4.794). This indicates that there is strong agreement for all of these conservation measures. There was marginally less support for 'zoos' with a mean of 4.739.

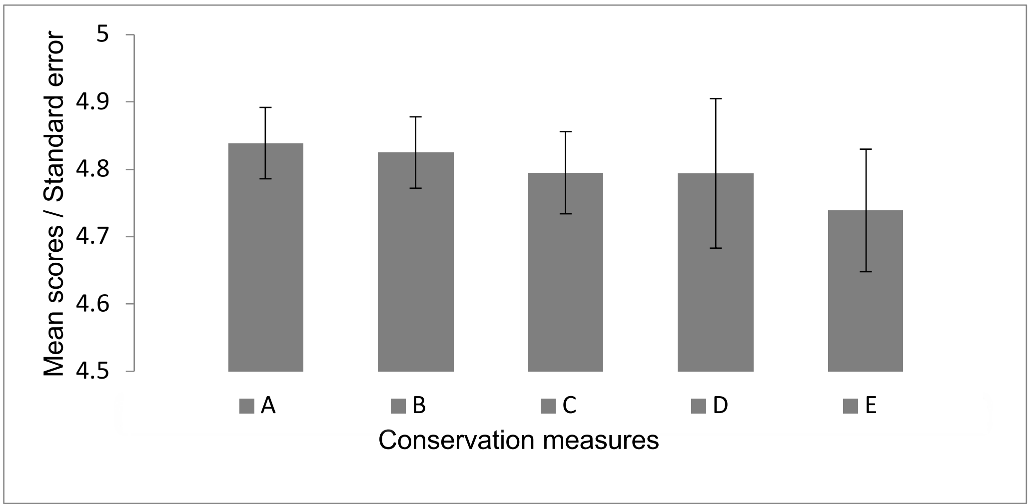


Fig. 4.9. Ranking of potential conservation measures that could have been used at the time of the 2015 survey, from the most to least important measures (grand means and standard errors). These are the opinions of respondents who were asked what would be the most effective Dorcas gazelle conservation measures that could be used at the present time in the Region South of Green Mountain. A = Protection laws, B = Education of all members of the community of the importance of wildlife, C = Protected areas (nature reserves), D = Captive breeding and reproduction of the gazelle, and E = Zoos. Means of Likert scores are shown with plus or minus standard error bars

Table 4.26 shows the percentage agreement of respondents about the effectiveness of proposed future conservation measures for Dorcas gazelle in the area south of Green Mountain. These results indicate that there is quite strong agreement on these conservation measures but there seems to be marginally less support for the ‘captive breeding and reproduction of the gazelle’. These values were almost identical for all respondent groups.

Table 4.26. Opinions of respondents on the likely effectiveness of future conservation measures for Dorcas gazelle

Conservation measure	Strongly disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly agree (%)	Mean Likert score
Protected areas (nature reserves)	0	0	0	7.7	92.3	4.921
Protection laws	0	0	0	10.8	89.2	4.895
Education of all members of the community of the importance of wildlife	0	0	0	18.5	81.5	4.834
Zoos	0	0.8	0	21.5	77.7	4.814
Captive breeding and reproduction of the gazelle	0	1.5	0.8	15.4	82.3	4.813

Figure 4.10 (based on grand mean values) classifies these measures by order of importance. The results indicate that there is strong agreement with the implementation of protected areas (nature reserves) with a mean score of 4.921, followed by protection laws (mean of 4.895), then education of all members of the community of the importance of wildlife (mean of 4.834) and zoos (mean of 4.814), but there was marginally less support for ‘captive breeding and reproduction of the gazelle’ with a mean of 4.813. These values were almost identical for all respondent groups.

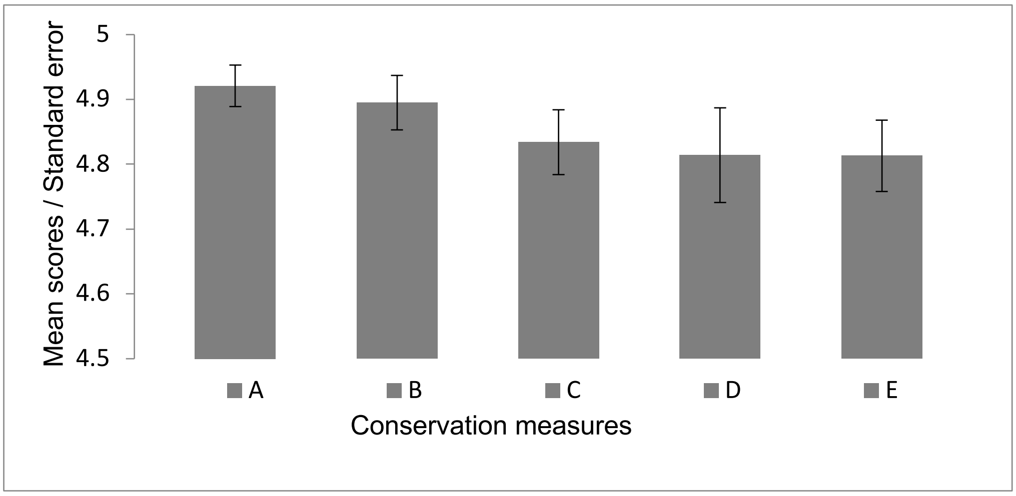


Fig. 4.10. Ranking of future conservation measures from the most to least important measures (grand means and standard errors) (2015 survey). These are the opinions of respondents who were asked what would be the most effective Dorcas gazelle conservation measures that could be used in the future in the Region South of Green Mountain. A = Protected areas (nature reserves), B = Protection laws, C = Education of all members of the community of the importance of wildlife, D = Zoos and E = Captive breeding and reproduction of the gazelle. Means of Likert scores are shown with plus or minus standard error bars

100% of respondents agreed that the measures above would provide effective protection of Dorcas gazelle populations in the study area. Figure 4.11 shows the groups and organisations they believe should have a role in the implementation and enforcement of these measures. It can be seen that the respondents, irrespective of age, education level and category, shared the same opinions on the role of different agencies in the protection of the species, but there was no support for ‘National Organizations’.

Fig. 4.11. Opinions of the respondents about which organisations should have a role in the implementation and enforcement of protection measures (Question 14)

The measures to conserve the Dorcas gazelle favoured by the respondents (open question no. 16) are shown in Table 4.27. As can be seen, all the respondents favoured the creation of an effective administration to implement protection policies and the enforcement of hunting laws. The vast majority were also in favour of the swift establishment of nature reserves in areas where gazelle live and the establishment of fenced areas to support the reproduction of Dorcas gazelle. Other measures that received high levels of support included a ban on hunting for at least five years, the regulation of hunting times and the banning of hunting during the reproductive period of the gazelle as well as the imposition of laws and penalties for those who do not obey the hunting laws.

Table 4.27. Respondents' views of the main priority/priorities and/or opportunities for conserving Dorcas gazelle in the study area, and the viability of restoring numbers to historical levels (open question 16) (2015 survey)

Items	No. of respondents (n = 130)	
	No	%
The creation of an effective administration able to implement protection policies	130	100
Cooperation with global bodies competent in this area (i.e. global conservation bodies)	41	31.5
The enforcement of hunting laws	130	100
A ban on hunting for at least five years	113	86.9
The regulation of hunting times and the banning of hunting during the reproductive period of the gazelle	113	86.9
The imposition of laws and penalties for those who do not obey the hunting laws	113	86.9
Raising the awareness within all members of Libyan society of the importance of wildlife using various media	27	20.8
The establishment of periodic seminars to educate people about the importance of wildlife	27	20.8
The establishment of nature reserves in areas where gazelle live as soon as possible	124	95.4
The establishment of protectively fenced areas in order to support the reproduction of Dorcas gazelle	122	93.8
Participation of local communities in protection	4	3.1

4.4. Chapter summary

The international conservation experts surveyed in this study had wide general knowledge and experience relating to the Dorcas gazelle, although they had little knowledge about its status in the study area in NE Libya. In contrast, the local stakeholders had considerable experience and knowledge of the gazelle in the area. Taken together, the views of both groups of respondents have contributed to an understanding of the current situation of the Dorcas gazelle across its range and in the study area in particular. The adoption of this research and data collection method was therefore justified.

From the questionnaire surveys, it is possible to reach the following main conclusions: (1) the number of Dorcas gazelle has decreased in the study area; (2) the most important factor that has led to the decline of Dorcas gazelle is overhunting, and this has increased during the ongoing conflict in Libya, which began in 2011, as result of the proliferation of firearms and the lack of security. In addition, this threat is closely linked to and overlaps with a lack of environmental awareness or appreciation of the value of the Dorcas gazelle on the part of citizens; (3) the number of sightings of individual Dorcas gazelles in the study area between 2011 and 2016 reported by the local stakeholders was 233. The opinions of the respondents regarding the effectiveness of a range of possible conservation measures for the Dorcas gazelle in the study area indicate strong support for a number of measures, especially the strengthening and enforcement of protection laws, the necessity for education of all members of the community regarding the value of wildlife and the establishment of protected areas. These measures will be taken into account in proposals for a viable conservation strategy appropriate for the study area.

The impact of three variables, age, level of education and category of respondent, on the experience and opinions of local stakeholder respondents was investigated. Overall, the analysis of these variables produced little differentiation between the respondents and achieved statistical significance only with regard to the following:

- The relationship between age and category of respondent and reported sightings of gazelle (both survey years).
- The relationship between age and estimates of the decline in the number of gazelle (2015 only).
- The relationship between level of education and category of respondent and reports of assaults on gazelle (2015 only).

The findings presented in this chapter will be critically discussed in detail in Chapter Seven.

Chapter Five: Field surveys for the assessment of the abundance of Dorcas gazelle

5.1. Introduction

The design of management programmes for gazelle populations requires exact estimates of their abundance (Marques *et al*. 2001). Both Witmer (2005) and Acevedo *et al*. (2010) stated that the appropriateness of the methods selected to assess abundance will be influenced by the ecology and behaviour patterns of the species, their estimated population, the nature of the habitat, and the resources available. Methods to estimate population abundance are broadly classified as direct and indirect (Acevedo *et al*. 2010). According to Gil-Sanchez *et al.* (2017), the two methods of field data collection which are most appropriate, and which have been most frequently employed, in gazelle surveys in arid and semi-arid areas are direct observations, or sightings, and counting indirect signs, such as tracks, isolated dung piles and latrines or middens. Both were used together in this study using Line Transect Distance Sampling. This study is the first to attempt to use this method to estimate Dorcas gazelle abundance in the semi-desert area of north east Libya, a very large area of approximately 16,700 km^2 containing an unknown number of this species.

Direct and indirect (observation of dung, tracks and other evidence) field investigations, methods subsequently validated by Gil-Sanchez *et al.* (2017), were undertaken in the summer of 2015 in areas where there were known gazelle populations and areas where there was potentially suitable habitat as established from the questionnaire surveys. After this initial survey, the survey methodology was refined to include a distance sampling method in a second summer survey in 2016. Distance sampling techniques have been widely used for a variety of species such as birds (Newson *et al*. 2008), cetaceans (Dick and Hines, 2011), small mammals (Newey *et al*. 2003) and ungulates (Focardi *et al*. 2005; Acevedo *et al*. 2008). Distance sampling (Buckland *et al*. 2001; 2004 and Thomas *et al*. 2010) is a practical and effective technique to estimate the size of animal populations (directly or indirectly) and is equally applicable to mountain slopes, wadis, and gravel or stony plains (El-Alqamy, 2003). A line transect sampling method, as suggested by Buckland *et al*. (2001), was designed for estimating the abundance of Dorcas gazelle populations in the study area. This approach is potentially more efficient and less prone to bias (Marques *et al*. 2001) than other approaches. The value of line transect sampling is that distances of detected pellet groups from the transect line can be measured (Marques *et al*. 2001; Smart *et al*. 2004; Thomas *et al*. 2010).

Although density estimates by habitat type were not of particular interest in this study, stratification by habitat type is usually required as the detection probabilities may vary according to the characteristics of the various habitats (Buckland *et al*. 2001). Hence, data on the habitat types associated with each transect line were also collected.

The specific aim of the field survey was to attempt to estimate the abundance of Dorcas gazelle in the study area, in order to inform the design of a management plan and conservation strategies for them. The objectives were to look for actual animals, to detect and count dung pellet groups and to investigate the rate at which dung decays.

5.2. Methods

5.2.1. Initial survey of gazelle distribution (summer 2015)

Buckland *et al*. (2001) suggested that in order to estimate population size, it is often most effective to focus on areas with a higher density of animals. Given the lack of detailed records relating to Dorcas gazelle in this region, and acknowledging that they may have been less than ideal, the key sources of information used for stratification were the results from the in-country questionnaire (Chapter Four) and an initial field survey, both conducted in August and September 2015.

The method used for this initial field survey resulted from an examination of the existing survey literature combined with the experience of the researcher and the supervisory team. As the area to be surveyed was potentially vast, none of the methods found in the literature satisfactorily blended the mix of scale and resolution required to investigate the species under study, so an innovative survey design was derived to address this.

There was a need for representative coverage of the study area (Fig. 5.1) to check for any presence of signs of gazelle so that appropriate effort could be allocated to the areas where the presence of gazelle was expected (highly populated areas as opposed to low-density areas). The choice of survey zones for this initial survey was informed by a previous study in 2007 (Algadafi, 2007) which had identified the presence of Dorcas gazelle in these zones. To facilitate the initial survey, the flat areas of the study region were divided into three separate sections, A, B, and C of

100 km^2 (10 km × 10 km) each which did not overlap (Fig. 5.1). Each of the 10 km x 10 km areas included 30 sample sites, based on coordinates determined using the 'Research Randomizer' software (Urbaniak and Plous, 2014) as shown in Fig. 5.2. Both the horizontal and vertical transect lines were spaced at 1 km intervals, with surveys being conducted along a transect band 2 m wide by 100 m long from each survey point in all four compass directions (Fig. 5.3).

In this survey, terrain and vegetation were noted individually at each survey site. Along each transect band, all observations of Dorcas gazelle, wildlife and livestock, including data on habitat, tracks and signs, were systematically recorded using a study-specific field sheet (Appendix 8).

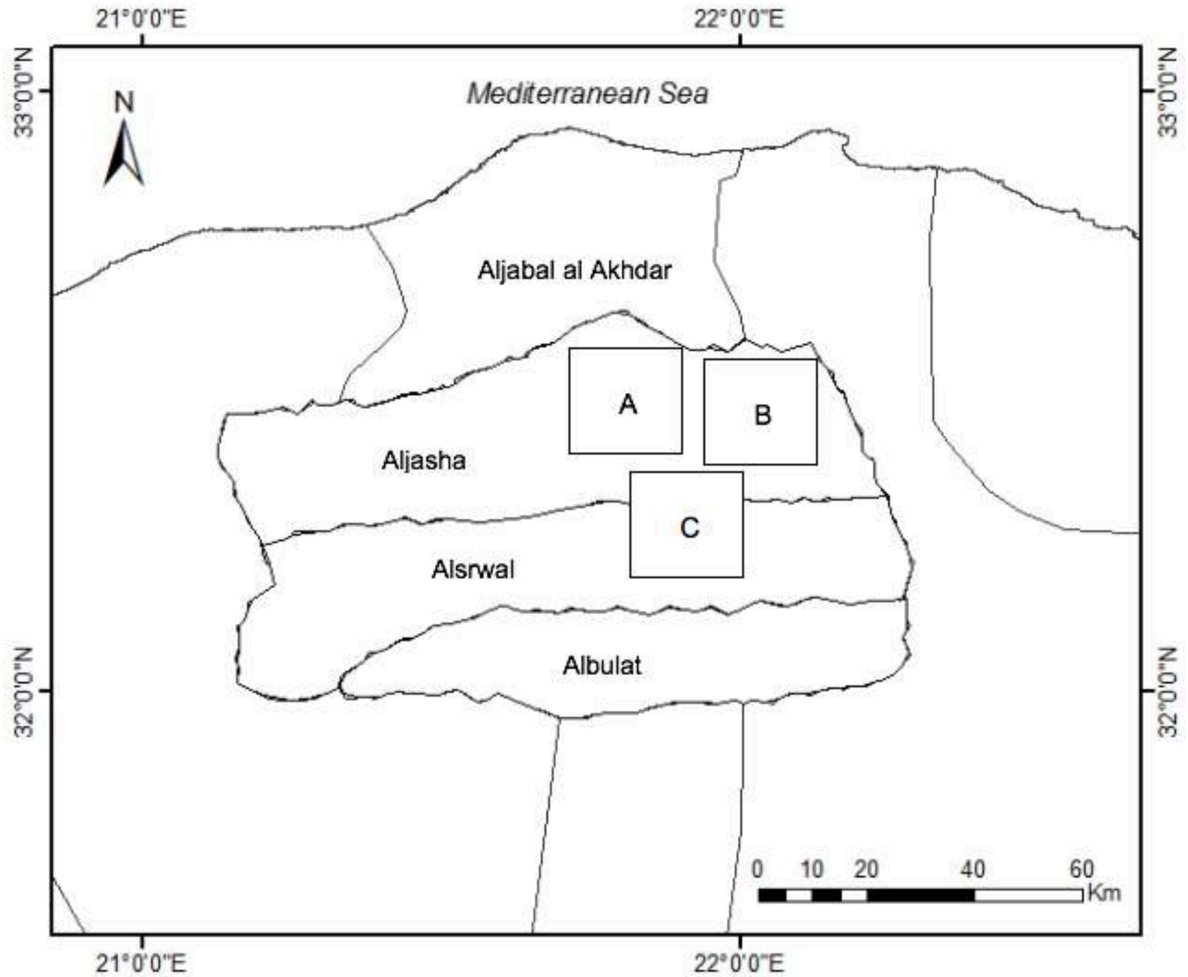


Fig. 5.1. Locations of the three survey areas A, B and C for the 2015 field survey within the study area (see also Fig. 5.2)

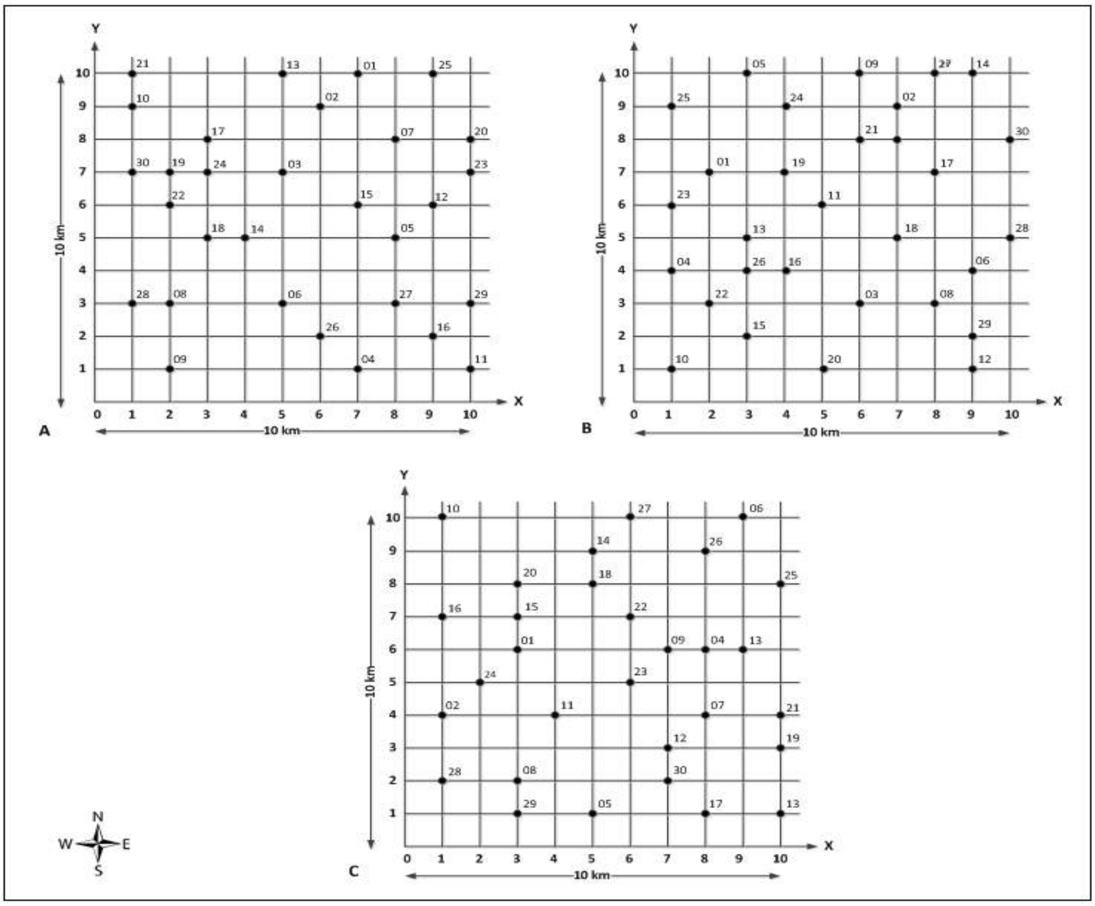


Fig. 5.2. Sampling locations for the three survey areas, based on coordinates determined using the 'Research Randomizer' software (Urbaniak and Plous, 2014)

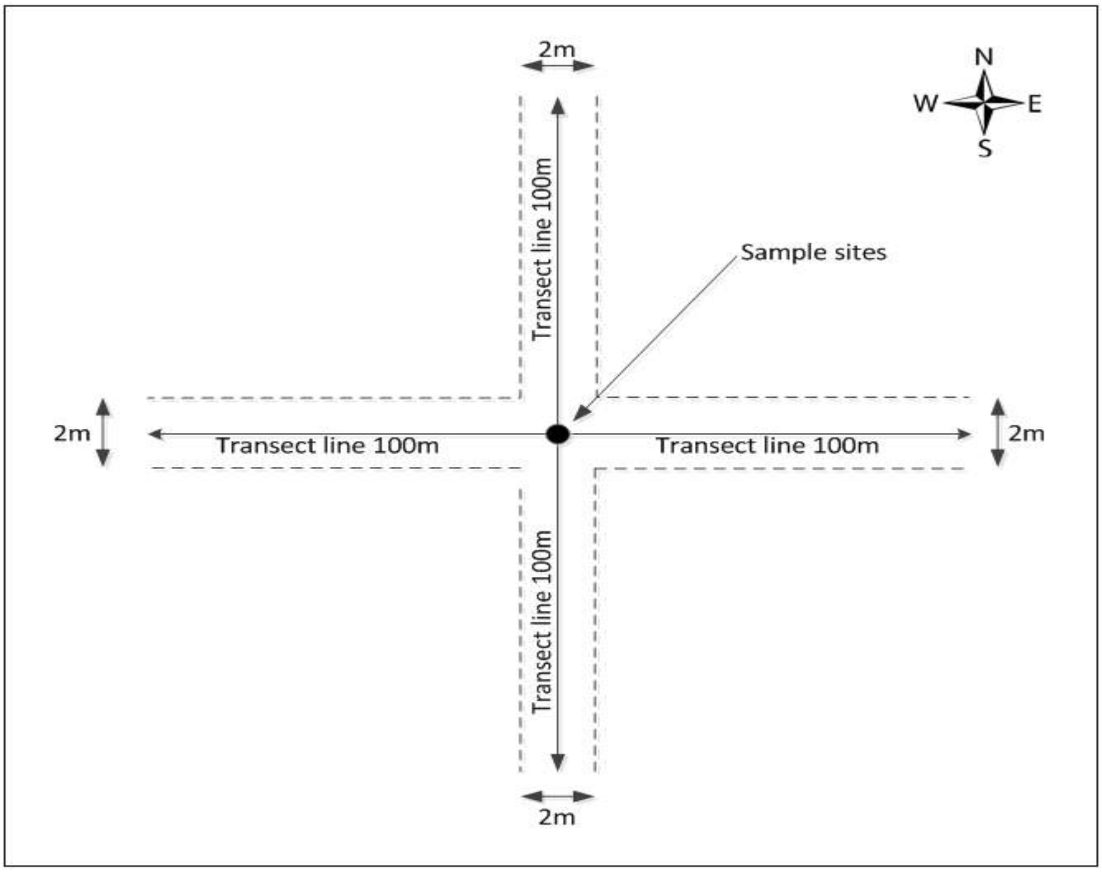


Fig. 5.3. Positioning of transect bands for each survey point

This survey, combined with information gained from the In-country questionnaire survey (2015), where the results of the in-country questionnaire indicated the recently-observed presence of small groups of wild gazelle in the Aljasha region, allowed the identification of high and low-density areas and this made it possible to stratify the study area into two strata (Fig. 5.4). The information obtained enabled the maximisation of spatial coverage and thus improved the precision of abundance estimates.

The high-density area is approximately 1,150 km^2 and is surrounded by the low-density area of about 15,550 km^2. The high-density area comprised rugged hilly terrain that is believed to be preferred by gazelle as it provides safe areas and food plants and may also provide some further protection from predators (Khattabi and Mallon, 2001). The surrounding area of plains and inner wadis was designated as the low-density stratum.

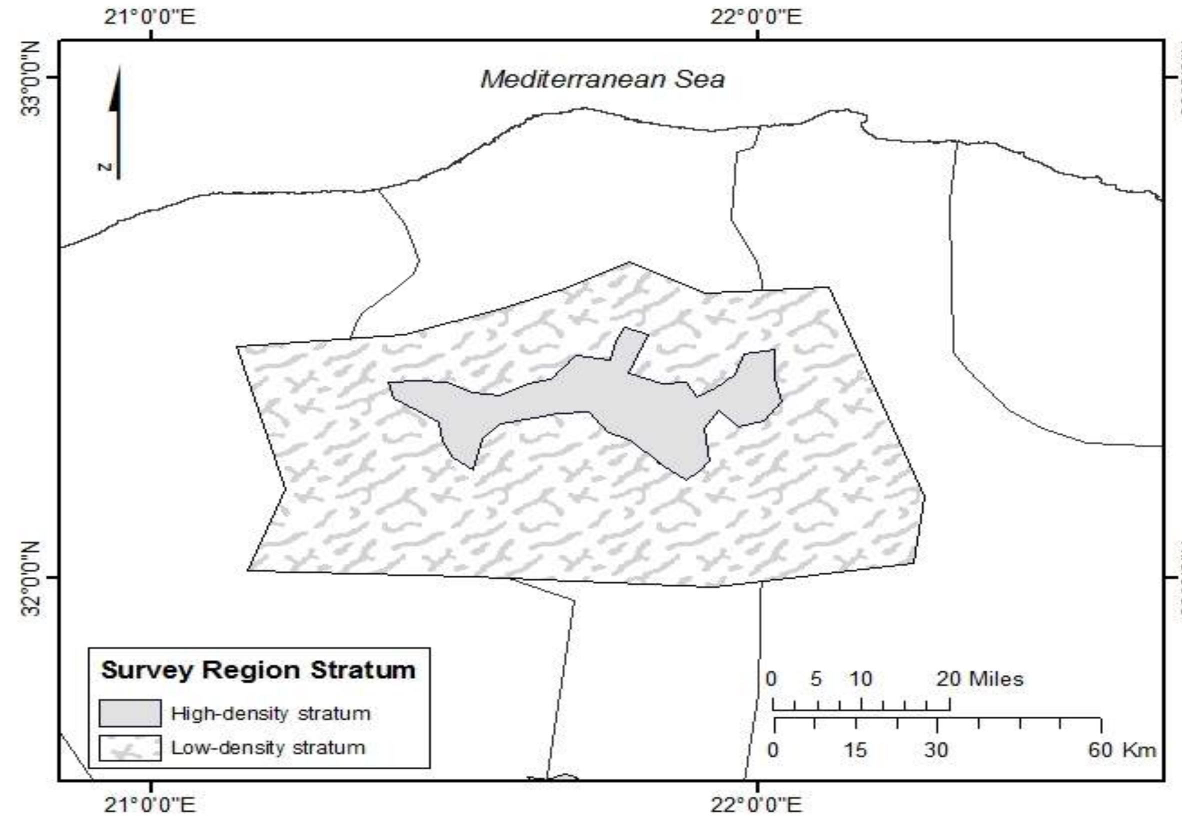


Fig. 5.4. Location of high and low-density strata of Dorcas gazelle in the study region

5.2.2. Survey design and method for distance sampling (summer 2016)

The initial plan had been to survey the whole study area using methods similar to those used in the 2015 survey. However, even though the 2015 fieldwork survey allowed for a structured survey of a significant area and produced some useful results, it was not as successful as anticipated and additionally it did not link effectively to methods for estimating populations. With this in mind and further evaluation of the key literature (e.g. by Buckland *et al*. 2001, 2004; El-Alqamy, 2003; Acevedo *et al*. 2010; Gil-Sanchez *et al.* 2017), a different approach of distance sampling dung deposits, was adopted for the August and September 2016 field survey, which was conducted in both the high- and low-density strata previously identified.

Surveys were conducted along 2 km transects with greater survey effort being focussed on the high-density areas, as described below. Gazelle dung deposits found to the left and right within 5 m of each transect were counted and recorded. According to Marques *et al*. (2001), when line transect sampling is used, it is not necessary to detect all pellet groups within a plot. A wide strip can be surveyed and “thus any potential bias from edge effects is reduced” (p. 350).

A hand-held global positioning (GPS) device (Garmin GPSMAP 64) was used to identify the locations of all signs of Dorcas gazelle. These locations were later added to the *ArcGIS* Geographic Information System (ESRI, 2017) in order to map areas where aggregations of gazelle signs occurred.

In distance sampling, the encounter rate and Coefficient of Variation (CV) can be used to produce estimates of abundance (Buckland *et al*. 2004). According to Smith *et al*. (2009), sampling should be intensive enough to produce a CV of approximately 15 to 30 percent. In the present study, the orientation of transect lines was determined by a map grid, so that lines ran North to South (Fig. 5.5). As there is considerable clustering and variation in the distribution of Dorcas gazelle throughout the study area, systematic segmented sampling was used to identify the distance sample transects. According to Buckland *et al*. (2001), this involves the random superimposition of a systematic set of segmented parallel lines onto the survey area. The lines were assigned according to the identified density strata. Since very few detections were expected in the low-density stratum, effort was focussed on the high-density stratum. Each North South transect line was divided into 2 km long transect segments with unsampled stretches in between them. The high-density area in the Aljasha region was much smaller than the low-density area and therefore the distance between transect segments was smaller to allow for greater sampling effort. Thus, transect segments were spaced with 1 km unsampled intervals between them in the high-density areas but in the low-density areas they were spaced 2 km apart (Fig. 5.6).

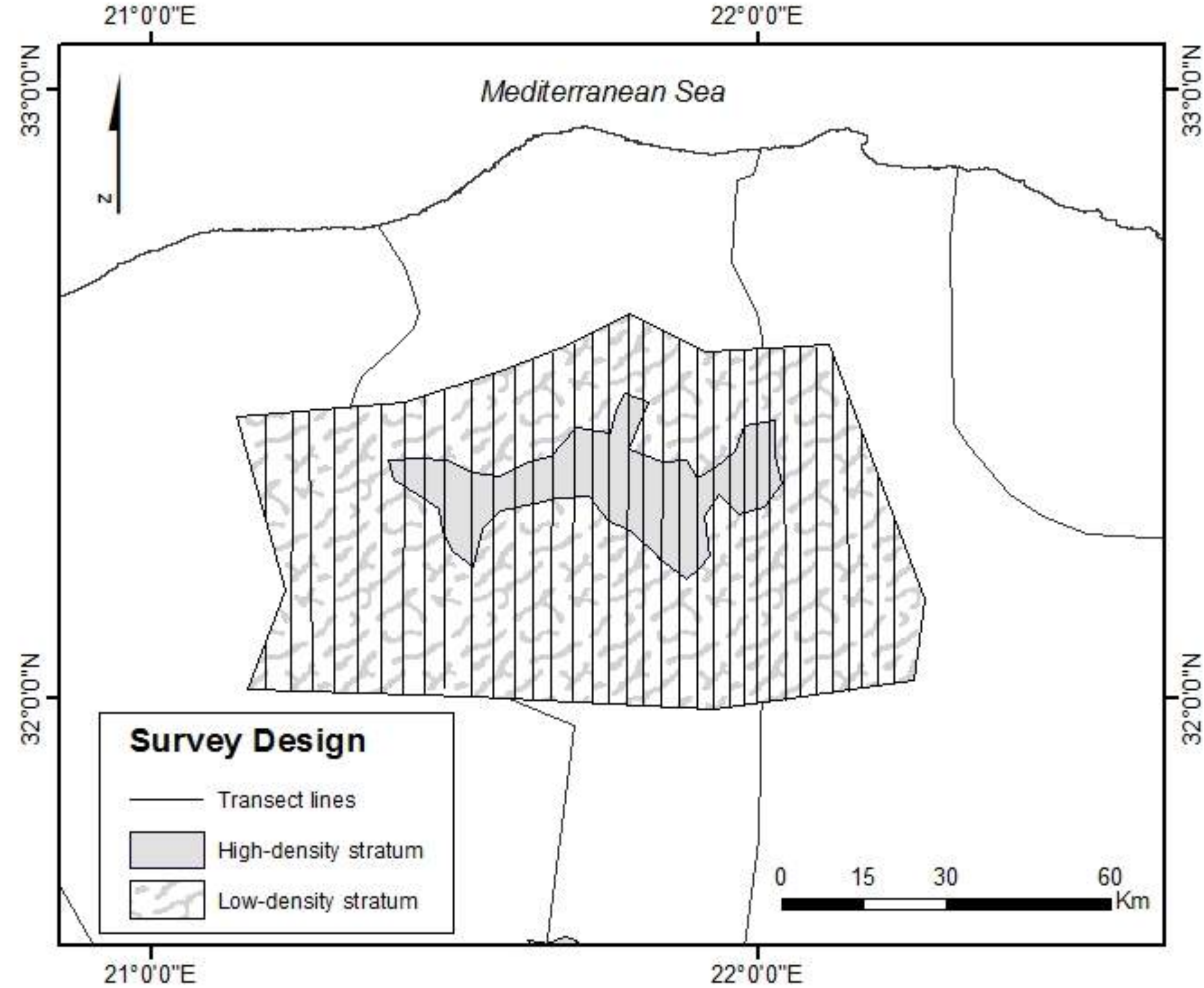


Fig. 5.5. Approximate location of survey transects in the study areas

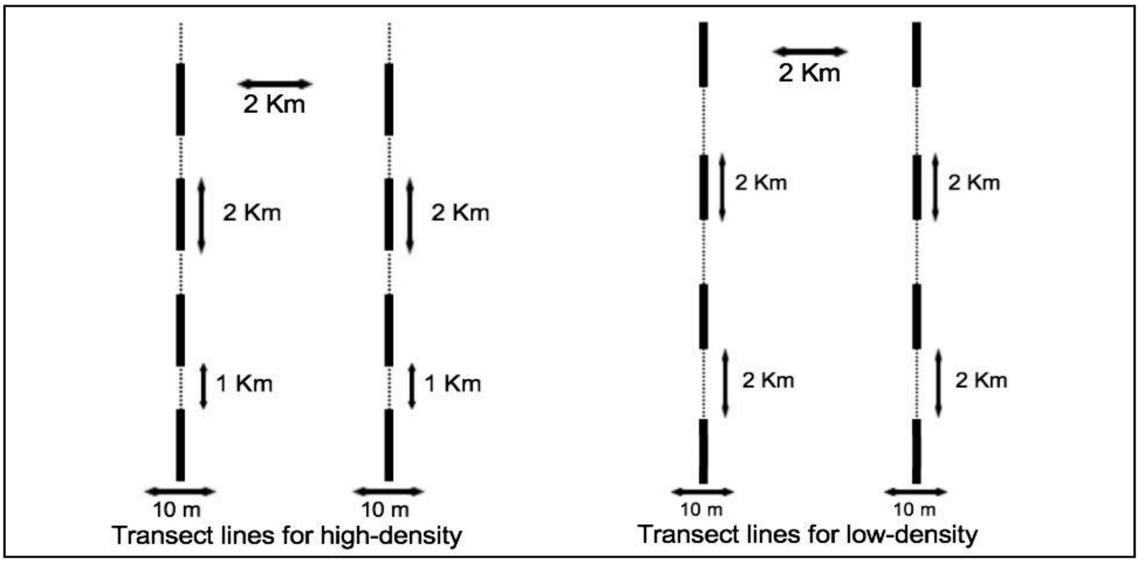


Fig. 5.6. Belt transect lines of 10 m widths, showing the spacing (dotted lines) between transect segments (solid lines). Transect segments were separated by 1 km in high- and 2 km in low-density areas

The survey comprised 250 x 2 km transect segments arranged parallel to each other and was undertaken on foot. The distance walked totalled 500 km. The exact location of the start and end points were identified to the nearest 1 m using the GPS device and recorded. In most locations, the transect width and lines were not strictly followed. Nineteen separate data collection forays were carried out in August and September 2016. The weather was good for each foray and no sampling was undertaken at night. The field sampling team was provided with general information about the aim of the study and what was required of them. The importance of accurate recording was emphasised, and they were instructed in the use of the GPS device.

Buckland *et al*. (2001) suggested that bias in line transect estimates tends to be small in terms of measurement errors, but larger when estimates are made from point transect surveys. In addition, El-Alqamy (2003) reported that experienced observers are an important asset to any study to prevent ending with biased population estimates.

The transects were surveyed by a three-person field sampling team who were all experienced both in the terrain and with the species: an observer, a recorder (the present author) and an assistant (see Plate 5.1). The observer walked ahead of the recorder and assistant, pulling a 20 m rope that acted as the reference point for the track line. Stops were made after a distance of 2 km. The team walked each transect once at ~2 km/h (i.e. a slow walking speed) and used a map, a compass and a tape measure to follow the transect line closely. The team were collected at the end of each transect and transported to the start of the next one by a 4WD vehicle.

Plate 5.1. Field team: an observer, a recorder (the author) and assistants in the study area (2016)

At the beginning of each transect segment the predominant habitat and terrain types within the segment were recorded and assigned to a category (Table 5.1) and any changes in habitat or terrain along the transect were also noted. Any other biota or items of interest were also recorded, as were date and duration. All signs of the presence of gazelle along these line transects, including tracks and faecal pellets, were noted. In addition, the number of pellets was counted, and the area of each dung pile was measured and recorded.

Table 5.1. Terrain/substrate and habitat categories used in this study

Category	Terrain	Category	Habitat
1	Valley (wadi)	1	Scattered Vegetation
2	Hilly ground	2	Dense, taller shrubs
3	Flat plain	3	*Capparis spinosa*
4	Plateau/gravel plain	4	*Haloxylon salicornicum* and *Retama raetem*
5	Rocky hills	5	Dwarf shrubs
6	Stony plains	6	*Peganum harmala*

The occurrence and location of all recently deposited gazelle dung pellets within 5 m on both sides of the transect were recorded as perpendicular distances to the rope. Pellet groups whose centres were located further than 5 m from the transect line were not counted to avoid bias. Distances from the rope were measured with a metal tape, and all were recorded to the nearest 1.0 cm. Marques *et al*. (2001) stated that one of the most important requirements in data collection is to avoid rounding the perpendicular distance measurements, and particularly distances near the transect line, to zero, so this was avoided.

The age of dung piles was estimated according to the six categories defined by El-Alqamy (2003) (Table 5.2). According to Mayle *et al*. (1999), the most effective means of being confident in the identification of the pellets of a species is to collect fresh pellets. Only relatively recent dung piles from categories 1, 2, 3 and 4 were recorded. Older dung from categories 5 and 6 was not recorded in order to improve the precision of abundance estimates by ensuring that gazelle had been recently present. The faecal samples from Dorcas gazelle were also used for DNA analysis (Chapter Six).

Table 5.2. Estimation and description of gazelle dung age (El-Alqamy, 2003)

Category	Description
1. Fresh dung	Characterised by its wet, shiny appearance, often accompanied by urine
2. Less than one-week old dung	Dark in colour and discrete in shape, with some sand sticking to the pellets
3. More than one week but less than one-month old dung	Dry and lacked a dark appearance
4. About one-month old dung	Light brown in colour, with longitudinal cracks
5. Old dung	Dry, scattered or mashed
6. Very old dung, white dung	Bedouin claim it is at least one old year if not older, so it is considered as the oldest droppings available

5.2.3. Data recording method

All direct and indirect observations, including data on habitat, vegetation, tracks and signs, were recorded on a study-specific field sheet (Appendix 9). All direct sightings of mammals and large birds, including group size and locations, were systematically recorded. When direct observations of Dorcas gazelle were made, the distance from the line of the transect was estimated. Estimation was needed as they were usually moving when first spotted and the background rarely had prominent landmarks or reference points. For both direct and indirect observations, the context was recorded in relation to the transect.

For a complete picture of conditions, basic daily weather data was collected in the field at one hourly intervals from 07.00 - 19.00 each working day and recorded on the study-specific field sheet.

5.2.4. The relationship between the density and abundance of dung and animal abundance

According to El-Alqamy (2003) and Valente *et al*. (2014) dung abundance can generally be related to the actual abundance of animals if the defecation rate (the amount of daily faeces deposited by an individual animal) and the dung decay rate (the period of time that faecal pellets remain on the ground in a detectable state) are known. For example, Barnes and Jenssen (1987) used this relationship between defecation rate and dung decay rate to estimate the abundance of elephants. They used the following equation:

$$N = \frac{\boldsymbol{N\ dung \times r}}{\boldsymbol{D}}$$

Where N_{dung} is the number of faecal pellets, r is the decay rate and D is the defecation rate.

The defecation rate and the dung decay rate can, therefore, be used to arrive at a direct estimate of the population size. Accordingly, the present study used this equation to estimate the abundance of Dorcas gazelle population in the study area.

To estimate the number and density of dung samples in the study area, DISTANCE 7.0 software (Thomas *et al*. 2010) was used in which indirect abundance and density estimates obtained through line transect surveys are converted to direct estimates of dung density. However, Swanson *et al*. (2008) pointed out that calculating the defecation rate of wild ungulates is extremely problematic. As far back as 1985, Mitchell *et al*. recommended that, until further research is undertaken in this area, published defecation rates should be used and this remains the case. In the study area, the defecation rate of wild Dorcas gazelle was not known, and it was not possible to empirically obtain it. This study therefore used the rate of 12.8 ± 0.70 daily defecations per individual as given in the literature for Dorcas gazelle for a captive population in Marlow Zoo in the UK (Cooke *et al*. 2016).

5.2.5. Calculation of the dung decay rate in the field

According to Marques *et al*. (2001), dung decay relates to the disappearance of a pellet of dung from an area regardless of the process which led to its disappearance. Laing *et al*. (2003) pointed out that the rate at which decomposition occurs is influenced by a large number of factors in the environment that can be very diverse. Examples of processes that can lead to dung decay include the covering of pellets with leaves, dispersion through trampling by wildlife, or organic decay. Dung is considered as decayed if an identifiable group of pellets is no longer visible (Marques *et al*. 2001).

In parts of the Aljasha area (the high-density area) and Albulat area (the low-density area) where the presence of gazelle dung was observed most frequently, five plots were selected (four plots in the high-density area and one plot in the low-density area) for the estimation of the rate of decay of gazelle dung. Selection was made taking into consideration the different habitat and terrain types present. The dimension of each plot varied according to the degree of spread of droppings, ranging between 20 x 20 cm and 60 x 60 cm. The initial number of droppings was counted for each plot, and each group of droppings was marked with a long stake, and its location relative to landmarks, such as pieces of vegetation or boulders within the plot, was mapped (Plate 5.2). Each plot was visited by a member of the survey team once per month for twelve months. During these monthly visits, the marked dung piles were counted, and the remaining amount was recorded as a percentage (100 x [1 - current pellet count / preceding month's pellet count]) (El-Alqamy, 2003). The results of these observations are set out in Appendix 10.

Plate 5.2. Reducing number of pellets in dung deposits in Plot 1 in a rugged area (see Fig. 5.16)

5.3. Data storage

Following completion of the survey, the data sheets were photocopied and scanned (as a pdf) before the data were entered onto an Excel spreadsheet. Only the data relating to Dorcas gazelle was entered on the spreadsheet which was then imported into the DISTANCE 7.0 software, following the procedure identified by Thomas *et al*. (2010). The column variables are defined in Table 5.3 (see Appendix 11 for a worked example – screenshot of data analysis within the DISTANCE programme). A further worksheet was created containing data relating to other species but not imported into the software.

Table 5.3. Definition of column variables which were imported into the DISTANCE 7.0 software

Spreadsheet column	Corresponding column in DISTANCE 7.0	Explanation
A	Study area: Label	Contains information that applies to the whole study
B	Region: Label	Name of stratum
C	Region: Area	Area of region (km^2)
D	Line transect: Line length	The length of each of 250 transects (metres)
E	Observation: Distance	Vertical distance from the line to dung cluster (metres)

5.4. Analysis of distance sampling data

The aim of using distance sampling was to estimate the abundance of Dorcas gazelle in the study area from the density of dung deposits. Thomas *et al.* (2010) identified three stages when analysing data in distance sampling: exploratory data analysis, followed by model selection and then final analysis and inferences. The first stage when analysing data in distance sampling is to operate the 'probability of detection' function. Version 7 of DISTANCE contains four different analysis engines, with increasing levels of sophistication, for estimating the probability of detection: Conventional Distance Sampling (CDS), Multiple-Covariate Distance Sampling (MCDS), Mark-Recapture Distance Sampling (MRDS), and Density Surface Modelling (DSM). All four analysis engines facilitate the estimation of density and abundance and can include stratification if desired. This study used the Conventional Distance Sampling (CDS) and Multiple-Covariate Distance Sampling (MCDS) analysis engines as recommended by Marques *et al*. (2007) and Thomas *et al*. (2010).

The four key functions available in Distance Sampling software are uniform, half-normal, hazard-rate and negative. These functions allow estimation of the detection probability of dung at given distances from the line transect. Only two key functions, the half-normal and hazard-rate functions, can be used with the CDS and the MCDS engines (for a fuller discussion, see Thomas *et al*. 2010).

In Conventional Distance Sampling (CDS) analysis, the detectability of objects of interest is only affected by the perpendicular distance to the transect line. However, in reality there are other factors that may affect the detection function, such as vegetation cover or variability between observers (Thomas *et al*. 2010). In the current study, many types of terrain were traversed in the study area, each of which had its own texture, colour and particle size. Also, the type and density of vegetation across the study area was highly variable, ranging from bare ground to scattered bushes. These inevitably introduce sources of variability into the detectability of gazelle droppings. To account for this variability the Multi Covariate Distance Sampling (MCDS) engine was also used. The difference between MCDS and CDS is the incorporation of covariates in addition to distance into the key function. The covariates used in this study were high and low-density. There are no pre-defined methods to evaluate and definitively determine the best model for the dataset. An analysis must be initiated by running several different models, with adjustment terms, in different combinations to determine the model that best fits the data. Using Akaike's Information Criterion (AIC), which is a measure of the closeness of fit of an estimated statistical model, will determine the model that best fits the data (Smith *et al*. 2009). Analysis using Distance 7.0 software is described in more detail in Buckland *et al*. (2001, 2004), Marques *et al*. (2001, 2007) and Thomas *et al*. (2010).

5.4.1. Estimating the detection function and model fitting

The perpendicular distances from the transect line to the dung locations were measured in the field and the resulting data was used in order to model the detection function and to fit the half-normal, uniform and hazard rate models. Different combinations of these models were used with the adjustment terms ‘Cosine’ and ‘Hermite polynomial’. The adjustment terms were selected sequentially using a likelihood ratio test and significance level of 0.15. Choice of the final model was based on a combination of a low Akaike’s Information Criterion (AIC) and a low variance (Marques *et al*. 2001; Buckland *et al*. 2004; Thomas *et al*. 2010).

The same detection function (global) was used for both the high- and low-density strata in the study area because very few detections were made in the low-density stratum. (For a fuller discussion of estimating detection function, see Marques *et al*. 2001, Buckland *et al*. 2004; Thomas *et al*. 2010).

5.5. Results

The fieldwork undertaken in August and September 2015 found no signs of the presence of Dorcas gazelle in areas of flat terrain in the survey areas delineated as A, B and C. However, during one survey visit, a group of three gazelles was sighted in the distant, more rugged part of the study area, where the broken ridges that hinder travel in this region also provide some refuge places for gazelles.

The field surveys undertaken in 2016 confirmed that Dorcas gazelle continued to exist in rugged terrain within the study area. Some well-used paths, tracks, and footprints were found (Plate 5.3) and dung was also found (Fig. 5.7), notably in areas of close proximity to livestock, principally camels (*Camelus dromedarius*), perhaps due to abundant vegetation in such areas.

Plate 5.3. Dorcas gazelle paths, tracks and hoof prints observed in the study area

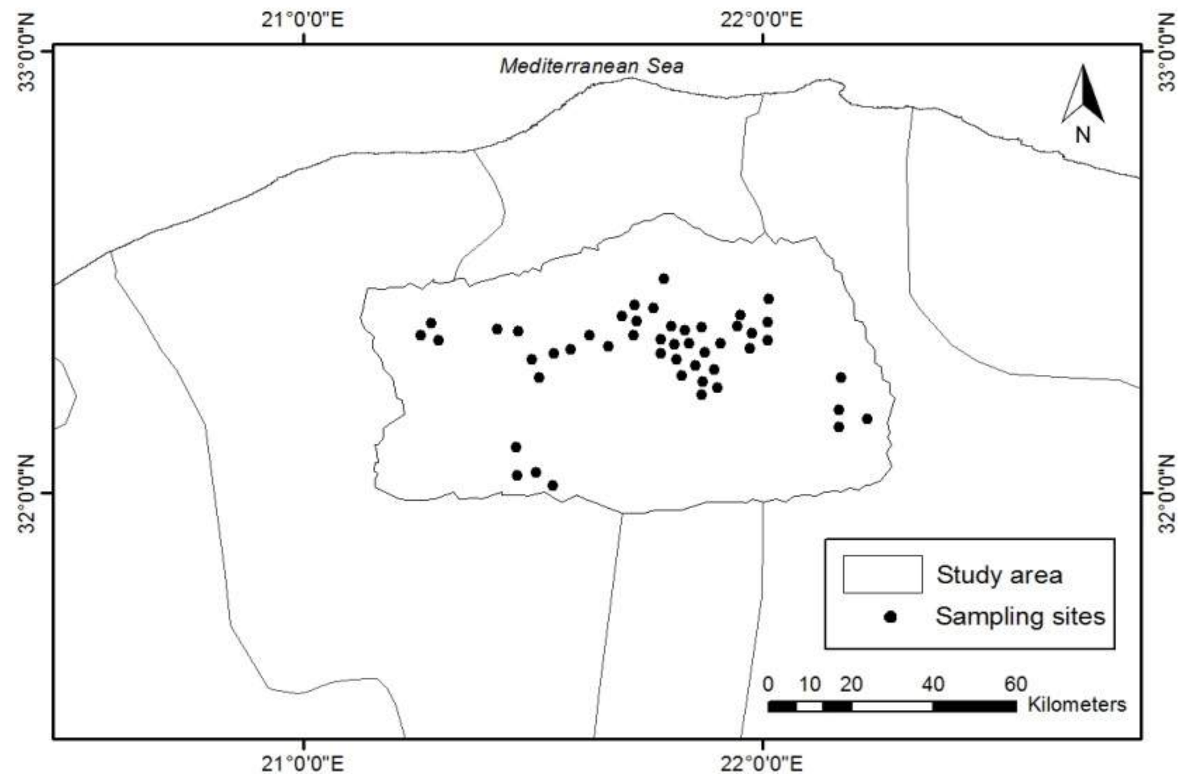


Fig. 5.7. Map of locations where Dorcas gazelle dung pellet groups were found in the study area

Table 5.4 shows the number of sites at which different indicators of the presence of Dorcas gazelle were found. Scattered dung pellets were the most frequently encountered indicators whilst gazelle sightings were the least frequent. 55 line transects were surveyed in valley areas and on 19 occasions indicators of the presence of Dorcas gazelle were found, making an average of 34.5% of transects on which indicators were found. Corresponding figures for hilly areas are 82 lines transect surveys, with indicators being found on 16 occasions (19.5%) and for flat plain areas, 113 surveys yielded indicators on 20 occasions (17.7%).

Table 5.4. The number and percentage of sites in the study area at which indicators of the presence of Dorcas gazelle were recorded (n = 250)

Type of data	No. of sites	% of sites
Sightings	4	1.6
Scattered dung pellets	30	12
Clustered dung pellets	18	7.2
Tissue	2	0.8
Head	1	0.4

5.5.1. Indirect indicators of the presence of Dorcas gazelle

Despite low numbers of Dorcas gazelle in the study area, during the survey of a total of 250 line transects, 51 samples were found, of which 48 were dung, two were physical tissue and one was a skull. Indications of the presence of gazelle were observed most frequently in the high-density stratum.

A total of 41 line transects were surveyed in high density strata and 209 in low density strata. The survey comprised 82 km of transects in high density areas and 418 km in low density areas. Only 6 groups of gazelle dung pellets were found in low density areas and 42 in high density areas. Figure 5.8 shows the age of the dung found. The most frequent age category found was 1 (fresh dung), and there was no dung found in categories 5 and 6 (old dung) (see Table 5.2 and Fig. 5.8). The two samples of fresh gazelle tissue and one head were found in low density areas.

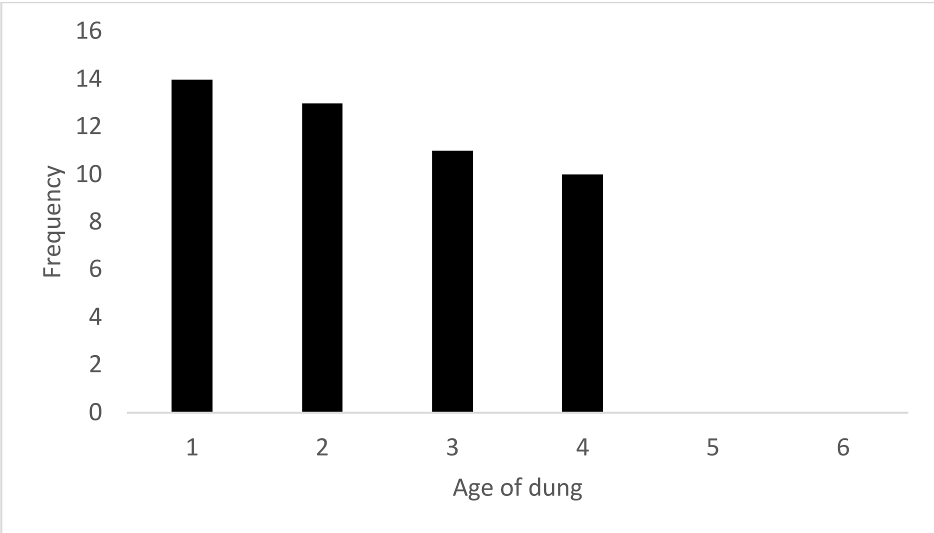


Fig. 5.8. Frequency of occurrence of each age category of dung (n = 48)

The number of dung pellets found in each group ranged from 9 to 53, with the most frequent being between 16 and 20 pellets (Fig. 5.9). Dung pellets were scattered in 62.5% of groups, while in 37.5%, they were clustered.

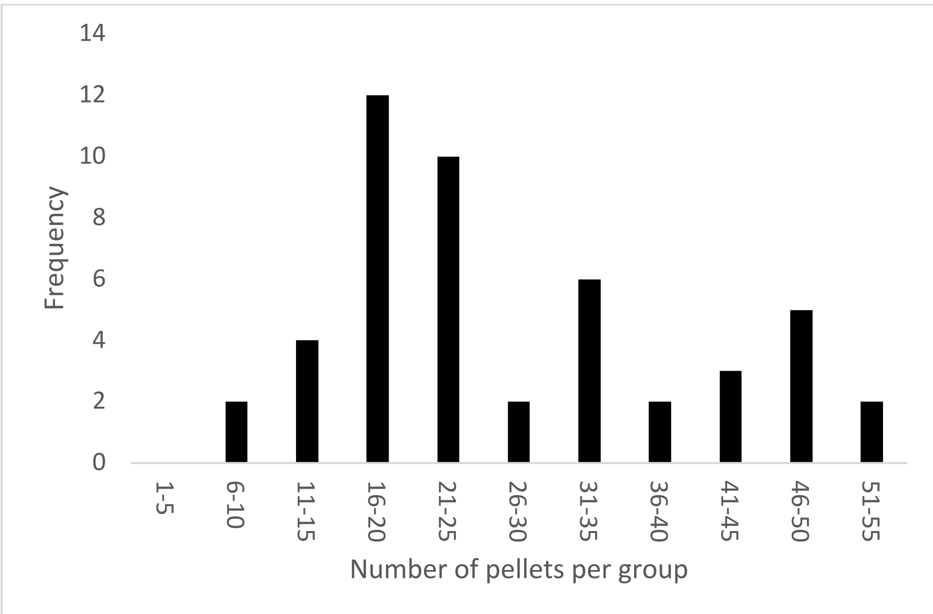


Fig. 5.9. Frequency of occurrence of pellets in each group (n = 1339)

The areas containing dung pellets ranged from 10 – 69 cm^2, (Fig. 5.10). The smallest area sizes were the most frequent.

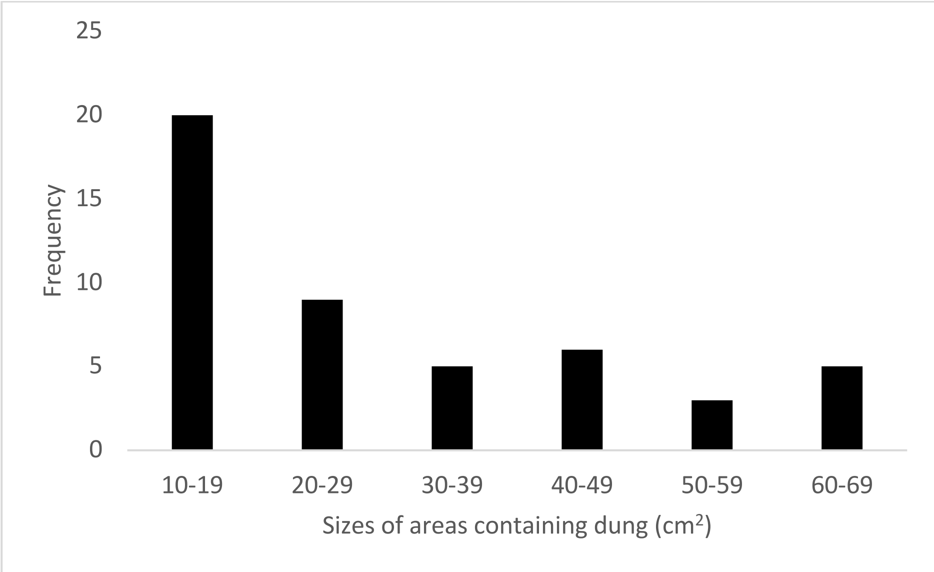


Fig. 5.10. Frequency of occurrence of the different size of areas containing dung (cm^2) (n = 48)

During the survey, two of the indicators of the presence of gazelle were physical in the form of tissue from the remains of freshly-butchered Dorcas gazelle (Plate 5.4). This was also evidence of hunting, as were the observed vehicle tracks, which may indicate hunting on a larger scale.

Plate 5.4. Physical indications of the presence of Dorcas gazelle in the study area in the form of butchered remains left by hunters (August and September 2016)

5.5.2. Direct indicators of Dorcas gazelle (sightings)

In the course of the 2016 survey, only four groups of Dorcas gazelle were sighted in twenty-one visits, comprising two, three, one and two animals respectively. It may be that the presence of the research team disturbed the gazelle and they avoided the areas. It was not possible to record the age and sex of the gazelle because they were observed in the distance or moving quickly away from the observers, so they could not be categorised. The locations of the gazelles sighted were far from the survey transects and were therefore estimated in relation to the transects. The estimated GPS location and group sizes were recorded (Table 5.5) and the locations of the Dorcas gazelle sightings are shown in Fig. 5.11. Dorcas gazelle were encountered in a fairly small area, but at marginally higher rates in the northern sectors of the Aljasha area. Sightings were made on 1.6 % of the 250 line transects (total distance of 500 km). Importantly, the results confirmed the continued presence of Dorcas gazelle in the study area 5 years after their presence was last established in 2011, immediately after the beginning of the conflict in Libya.

Table 5.5. Summary of sightings of Dorcas gazelle, during August and September 2016

No. of gazelle sighted	Behaviour	General habitat	Topography	Substrate	Latitude (N)	Longitude (E)
2	Running	Semi desert	Flat plain	Rocks	32° 19' 47.9''	021° 51' 17.1''
3	Running	Semi desert	Valley	Rock and sandy soil	32° 13' 16.4''	021° 32' 42.5''
1	Running	Semi desert	Valley	Rock and sandy soil	32° 18' 20.4''	021° 52' 07.2''
2	Running	Semi desert	Hill	Rock and sandy soil	32° 24' 69.1''	021° 43' 72.7''

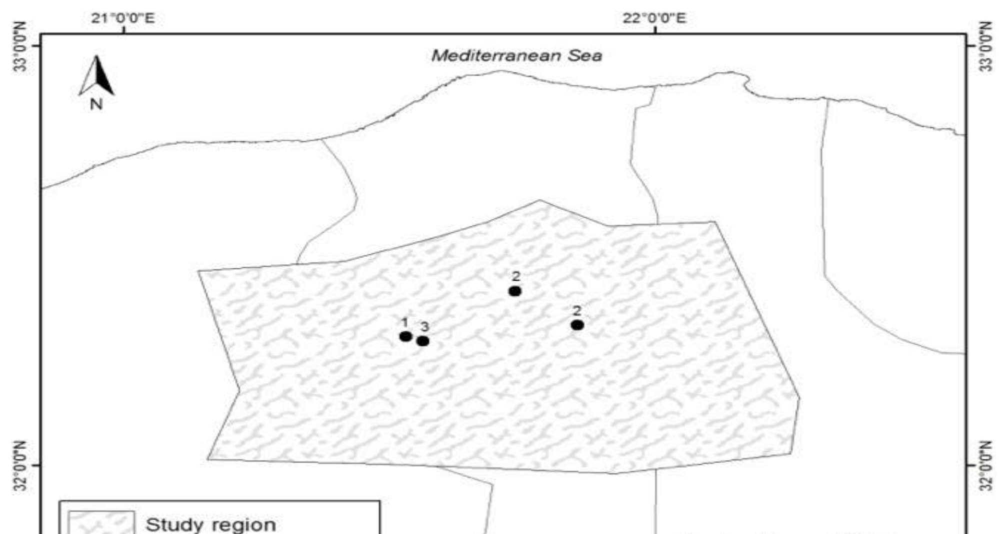


Fig. 5.11. Number and location of gazelles sighted in the study area, during August and September 2016

5.5.3. Associated fauna and wildlife

Sheep and goats were the most widespread and abundant livestock, while camels and cows were also recorded frequently in the study area (Table 5.6).

Table 5.6. Summary of fauna recorded along the entire transect surveys (Estimated numbers), during August and September 2016

Estimated numbers								
Species	Gazelle	Bustards	Camels	Sheep	Goats	Cows	Jackals	Rabbits
Total	8	3	220	1585	880	125	12	5

5.5.4. Vegetation in the sampled area

85.6% of the transects had low-density scattered patches of vegetation, with shrubs being the dominant form of vegetation. In the remaining 14.4%, additional, medium-density cover was provided by trees, with the species *Juniperus phoenicea* being the most dominant. The dominant species of shrubs and trees at the 250 recording points are shown in Table 5.7.

Haloxylon salicornum and *Retama raetam* were both widespread and frequent. There were also the regular but more isolated occurrences of potentially important browse species for gazelle such as *Capparis spinosa* and *Anabasis articulata*. In many places, the shrub layer included a fresh sward of young *Pituranthos tortuosus*, with *Atriplex rosea*, *Sarcopoterium spinosum*, *Peganum harmala* with smaller plants providing a rich grazing layer, among them *Thymus capitatus* and *Artemisia herba-alba*.

Table 5.7. Dominant plant species at 250 recording sites, during August and September of 2015 and 2016

Family	Scientific name	Local name	Number of sites
Rhamnaceae	*Rhamnus tripartita*	Salof	2
Brassicaceae	*Matthiola longipetala*	Shkarh	7
Anacardiaceae	*Rhus tripartita*	Gdare	12
	Didymus bipinnatus	Lsls	13
Asclepiadaceae	*Periploca angustifolia*	Halab	15
Cupressaceae	*Juniperus phoenicea*	Arar	16
Polygonaceae	*Polygonum equisetiforme*	Kartab	20
Nitrariaceae	*Peganum harmala*	Harmal	28
Thymelaeaceae	*Thymelaea hirsuta*	Methnan	36
Rhamnaceae	*Ziziphus lotus*	Cedar	38
Lamiaceae	*Thymus capitatus*	Zater	38
Asteraceae	*Artemisia herba-alba*	Sheah	38
Capparaceae	*Capparis spinosa*	Kabbar	39
Amaranthaceae	*Anabasis articulata*	Agram	40
Rosaceae	*Sarcopoterium spinosum*	Shbrek	61
Chenopodiaceae	*Atriplex rosea*	Kataf	64
Umbelliferae	*Pituranthos tortuosus*	Kazah	98
Fabaceae	*Retama raetam*	Ratem	99
Chenopodiaceae	*Haloxylon salicornum*	Rameth	139

5.5.5. Distance sampling data analysis

5.5.5.1. Detection function

The data was first analysed using the CDS analysis. The CDS detection function was tested using the half-normal and hazard-rate functions. Perpendicular distances were grouped in intervals corresponding to the detection function intervals and observations were truncated at 5 m. Interval cut points and goodness of fit (GOF) parameters, as chosen by the programme are shown in Tables 5.8, 5.9 and 5.10 for each of the three Chi-square tests applied by the software. The habitats and type of terrain in the study area are very similar, especially in the high-density region and only 6 piles of dung were detected in the low-density stratum. For this reason, a global detection function was used for all terrain types and all sets of data, incorporating all of the co-variates, with no separate co-variates according to habitat and type of terrain. This test looks at the distribution of dung samples in the 5 meter distance from the transect line, by dividing the distance into 4, 6 and 10 intervals and seeing which fit is best.

Table 5.8. Detection Fct/Global/Chi-sq GOF Test 1. Interval cut points used to fit detection function

Cell	Cut Points		Observed Values of dung samples	Expected Values	Chi-square (X^2) Values
1	0.000	1.17	10	12.00	0.333
2	1.17	2.35	15	12.00	0.750
3	2.35	3.52	9	12.00	0.750
4	3.52	4.70	14	12.00	0.333

Total chi-square value = 2.1667, and degrees of freedom = 2.00
Probability of a greater chi-square value, P = 0.33847

Table 5.9. Detection Fct/Global/Chi-sq GOF Test 2. Interval cut points used to fit detection function

Cell	Cut Points		Observed Values of dung samples	Expected Values	Chi-square (X^2) Values
1	0.000	0.783	8	8.00	0.000
2	0.783	1.57	7	8.00	0.125
3	1.57	2.35	10	8.00	0.500
4	2.35	3.13	8	8.00	0.000
5	3.13	3.92	5	8.00	0.125
6	3.92	4.70	10	8.00	0.500

Total chi-square value = 2.2500, and degrees of freedom = 4.00
Probability of a greater chi-square value, P = 0.68989

Table 5.10. Detection Fct/Global/Chi-sq GOF Test 3. Interval cut points used to fit detection function

Cell	Cut Points		Observed Values of dung samples	Expected Values	Chi-square (X^2) Values
1	0.000	0.470	6	4.80	0.300
2	0.470	0.940	3	4.80	0.675
3	0.940	1.41	4	4.80	0.133
4	1.41	1.88	8	4.80	2.133
5	1.88	2.35	4	4.80	0.133
6	2.35	2.82	7	4.80	1.008
7	2.82	3.29	2	4.80	1.633
8	3.29	3.76	3	4.80	0.675
9	3.76	4.23	2	4.80	1.633
10	4.23	4.70	9	4.80	3.675

Total chi-square value = 12.0000, and degrees of freedom = 8.00
Probability of a greater chi-square value, P = 0.15120

An unexpected effect was found when the CDS detection function of the software was used. Even though half-normal and hazard rate models were specified, the resulting graph had the appearance that suggested a uniform model had been used (Figs. 5.12, 5.13 and 5.14). The data showed no sign of a decline in detections with distance. One possible explanation for this is that the scale parameter of the detection function is estimated to be very low - it is also a small dataset.

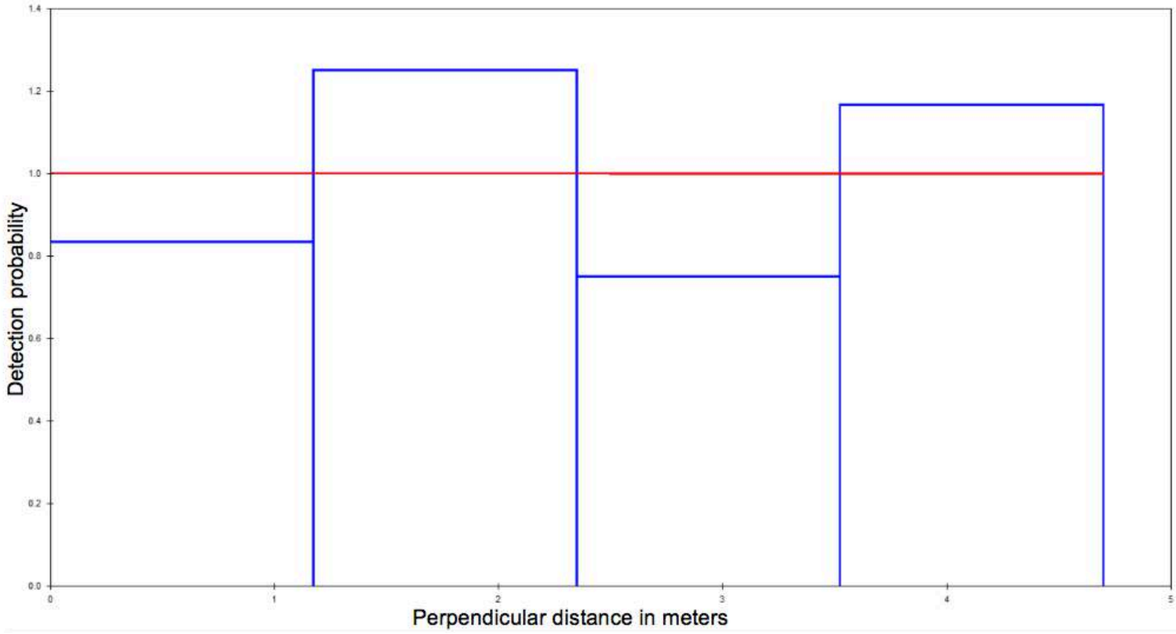


Fig. 5.12. Detection probability 1. Preliminary global detection function for Dorcas gazelle dung with distance from line transects in the study area. The red line is the probability of detecting dung away from the centre of the transect (i.e. the Detection Function) and the columns are the distance bins used to group the distance observations in the modeling process of the detection function

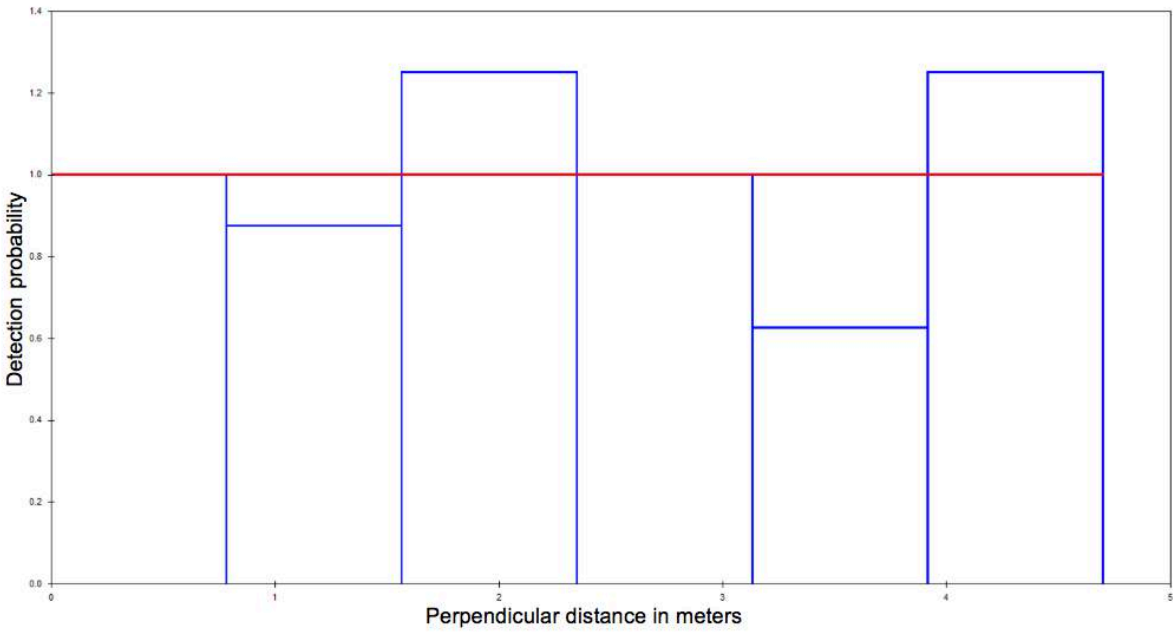


Fig. 5.13. Detection probability 2. Preliminary global detection function for Dorcas gazelle dung with distance from line transects in the study area. The red line is the probability of detecting dung away from the centre of the transect (i.e. the Detection Function) and the columns are the distance bins used to group the distance observations in the modeling process of the detection function

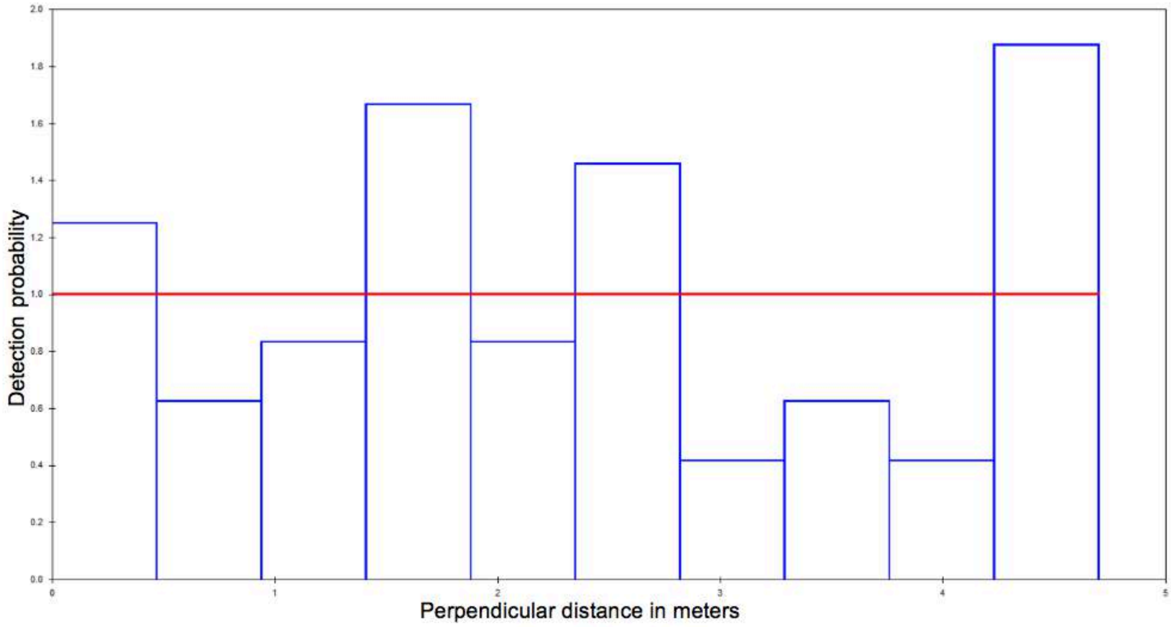


Fig. 5.14. Detection probability 3. Preliminary global detection function for Dorcas gazelle dung with distance from line transects in the study area. The red line is the probability of detecting dung away from the centre of the transect (i.e. the Detection Function) and the columns are the distance bins used to group the distance observations in the modeling process of the detection function

The ‘cosine’ and ‘hermite polynomial’ adjustment terms were applied to the hazard rate and the half-normal functions and the results are shown in Table 5.11. The consistently lower akaike information criterion (AIC) scores indicate that the half-normal key generally provided a better fit with the data. As a result of achieving the lowest AIC value (150.57), the half-normal model was selected. Model fit parameters and point estimates (f) are listed in Table 5.12.

Table 5.11. Key functions used to fit detection function in the study area

Key function	Adjustment term	No. of parameters	AIC value
Half-normal	Cosine	2	150.57
Half-normal	Hermite polynomial	1	152.56
Hazard Rate	Cosine	2	152.57
Hazard Rate	Hermite polynomial	1	154.57

Table 5.12. Half-normal/cosine key. Model fit parameters and point estimates for the field detection function (Estimate of the detection probability)

Parameter	Point Estimate	Standard Error	Percent Coef. of Variation (%CV)	df	95% Percent Confidence Interval	
m	1.0000	-	-	-	-	
AIC	150.57	-	-	-	-	
Chi-P	0.33847	-	-	-	-	
A(I)	3129.	0.6067E+09	-	-	-	
f(0)	0.21277	0.31015E-01	14.58	47.00	0.15893	0.28483
P	1.0000	0.14577	14.58	47.00	0.74698	1.0000
ESW	4.7000	0.68513	14.58	47.00	3.5108	6.2920

Effort: 500 km. No. of samples: 250. Width: 4.7 m. No. of observations: 48
m = number of parameters in the model. Chi-p = probability for chi-square goodness-of fit test. A(**I**) = parameter in the estimated probability density function (pdf). *f*(0) = value of pdf at zero for line transects. P = probability of observing an object in defined area. ESW = for line transects (m), effective strip width

Inspection of Tables 5.8, 5.9 and 5.10 and the detection function plot reveals that the detection function does not have a particularly good fit with the data, as indicated by the relatively large χ^2 value. The detection function (Figs. 5.12, 5.13 and 5.14) resulted in a straight line (shown in red on the graphs), as if a uniform model had been used rather than the half-normal and hazard rate models. Thus, an alternative form was investigated for the detection function.

As the detection probability resulting from the CDS is clearly a very poor fit in the half normal model, it is conceivable that a different form of detection function using MCDS would provide a better fit with the data and reduce the AIC value for this dataset. A comparison of the results obtained using conventional distance analysis (CDS) and multi-covariate analysis (MCDS) in the study area was therefore undertaken.

The Akaike Information Criterion (AIC) was also used to compare the two models. The same interval cut-points as in the half normal model and truncation at 5 m were used and the results obtained are listed in Table 5.13. The test shows that the MCDS detection function is a better model with lower AIC values.

Table 5.13. Fit parameters comparing detection function using CDS and MCDS in the study area

Model	AIC	Detection function (*f*)	CV%	95% Percent Confidence Interval	
CDS	150.57	0.21277	14.58	0.15893	0.28483
MCDS	148.39	0.20643	27.74	0.11929	0.35722

As only 6 piles of droppings were detected in the low-density stratum, the two sets of data (high and low-density) were analysed globally using the MCDS detection engine. The observations were truncated at 5 m and interval cut points and goodness of fit parameters were selected by the programme. The detection function, as shown in Fig 5.15, reveals the expected decline in encounter rate from the transect line with a spike of detections at 1.5 m, 2.5 m and 4.5 m and this was accepted.

Cosine adjustment terms were applied to the half-normal and the hazard rate functions. The half-normal function resulted in lower AIC values than any of the hazard rate functions. However, adding the adjustment terms did not reduce the AIC values. As a result, the half-normal function without adjustment was chosen as the model for the detection function. The interval cut points and goodness of fit parameters are shown in Table 5.14. A more satisfactory fit was obtained, with a substantially reduced chi-square value (χ^2) (Table 5.14). Point estimates and the model parameters are shown in Table 5.15.

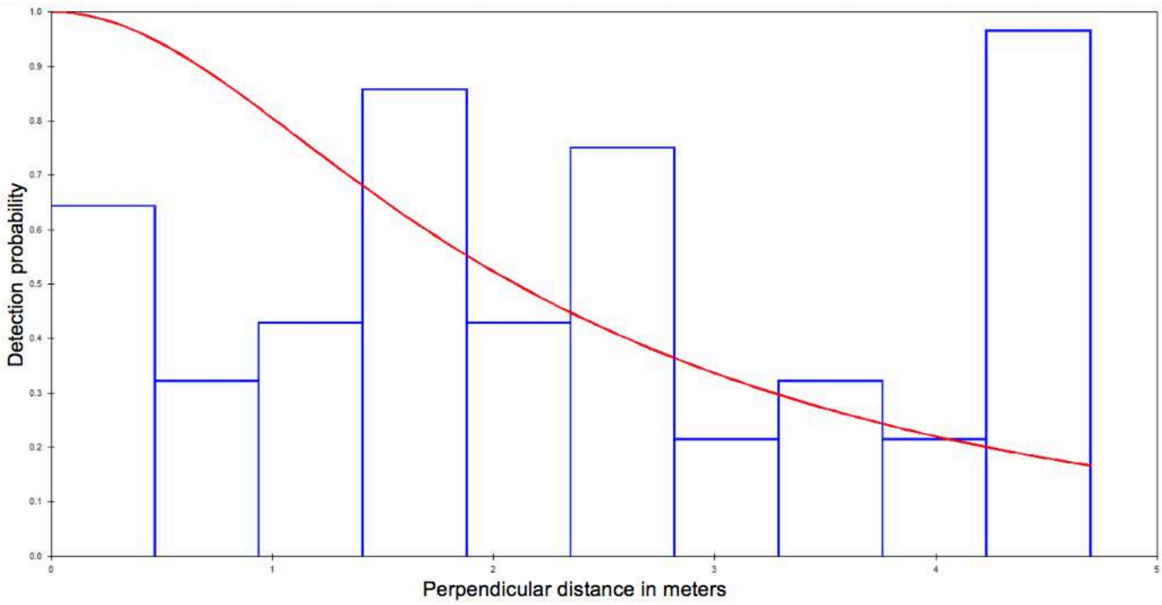


Fig. 5.15. Detection probability. Preliminary global detection function (high- and low-density data combined) for Dorcas gazelle dung with distance from line transects in the study area. The red line indicates the probability of detecting dung away from the centre of the transect (i.e. the Detection Function) and the columns are the distance bins used to group the distance observations in the modeling process of the detection function. Changing these bins can significantly affect the shape of the detection function

Table 5.14. Detection Fct/Global/Chi-sq GOF Test. Intervals cut points used to fit detection function

Cell	Cut Points		Observed Values of dung samples	Expected Values	Chi-square (X^2) Values
1	0.000	0.470	6	4.51	0.313
2	0.470	0.940	3	4.06	0.275
3	0.940	1.41	4	4.48	0.051
4	1.41	1.88	8	6.02	0.648
5	1.88	2.35	4	6.82	1.169
6	2.35	2.82	7	5.26	0.574
7	2.82	3.29	2	2.63	0.149
8	3.29	3.76	3	2.05	0.445
9	3.76	4.23	2	4.59	1.465
10	4.23	4.70	9	7.58	0.267

Total chi-square value = 5.5346, and degrees of freedom = 6.00
Probability of a greater chi-square value, P = 0.47728

Table 5.15. Half-normal/cosine key. Model fit parameters and point estimates of field detection function (Estimate of the detection probability)

Parameter	Point Estimate	Standard Error	Percent Coef. of Variation (%CV)	df	95% Percent Confidence Interval	
m	3.0000	-	-	-	-	
AIC	148.39	-	-	-	-	
Chi-P	0.47728	-	-	-	-	
A(I)	3129.	0.1443	-	-	-	
f(0)	0.20643	0.57265	27.74	45.00	0.11929	0.35722
P	0.97210	0.28593	27.74	45.00	0.59561	1.0000
ESW	4.8443	1.3439	27.74	45.00	2.7994	8.3831

Effort: 500 km. No. of samples: 250. Width: 4.7 m. No. of observations: 48
m = number of parameters in the model. Chi-p = probability for chi-square goodness-of fit test. A(**I**) = parameter in the estimated probability density function (pdf). *f*(0) = value of pdf at zero for line transects. P = probability of observing an object in defined area. ESW = for line transects (m), effective strip width

In the light of these findings, it was decided to adopt the MCDS approach to model detectability and as the best method to obtain density estimates in the current study.

5.5.5.2. Global dung density estimates

Dung density was estimated using the detection functions described in section 5.5.5.1. A summary of the estimates is shown in Table 5.16. The best fit detection function gave an estimate of 36820 pellets in the study area, this is the value that was then used to input to the population estimate equation. The global density estimate is the mean of the estimate of both strata (high- and low-density). The software also provided percentages for the estimated variance in detection probability and the encounter rate (Var D), which were 78.4% and 21.6% respectively. However, only 48 groups of dung were encountered in the entire survey, so these results must be interpreted with caution.

Table 5.16. Half-normal/cosine. Dorcas gazelle dung density/abundance estimates

Parameter	Estimate	Standard Error	Percent Coef. of Variation (%CV)	df	95% Percent Confidence Interval	
D	9.9085	3.1053	31.34	72.30	5.3831	18.238
N	36820.	11539.	31.34	72.30	20004.	67773.

Effort: 500 km. No. of samples: 250. Width: 4.7 m. No. of observations: 48
D = estimate of density of dung. N = estimate of number of dung pellets in a specified area

5.5.5.3. Estimated dung decay rate

Five plots were identified in the high- and low-density regions to investigate how rapidly dung decayed (see section 5.2.5). Over a 12-month period there was no change in the number of pellets until the third month, but a decline was observed in all plots from the fourth month. Plot 5 in the low-density region (sandy habitat), showed 100% decay after 12 months, while in the rest of the plots (rugged habitat), the decay was up to 90%. Figure 5.16 shows the dung decay rate over a period of 12 months as a percentage of dung remaining on the ground in plots 1 to 5. The global predicted annual estimate for the dung decay rate was about 37.2%.

5.5.5.4. Estimate of the abundance of the Dorcas gazelle population

The defecation rate (D = 12.8 ± 0.70), the number of dung (N_{dung} = 36820, see Table 5.16) and the dung decay rate (r = 37.2%) would suggest an estimated population for Dorcas gazelle in the study area of 1070 individuals (equation provided in section 5.2.4).

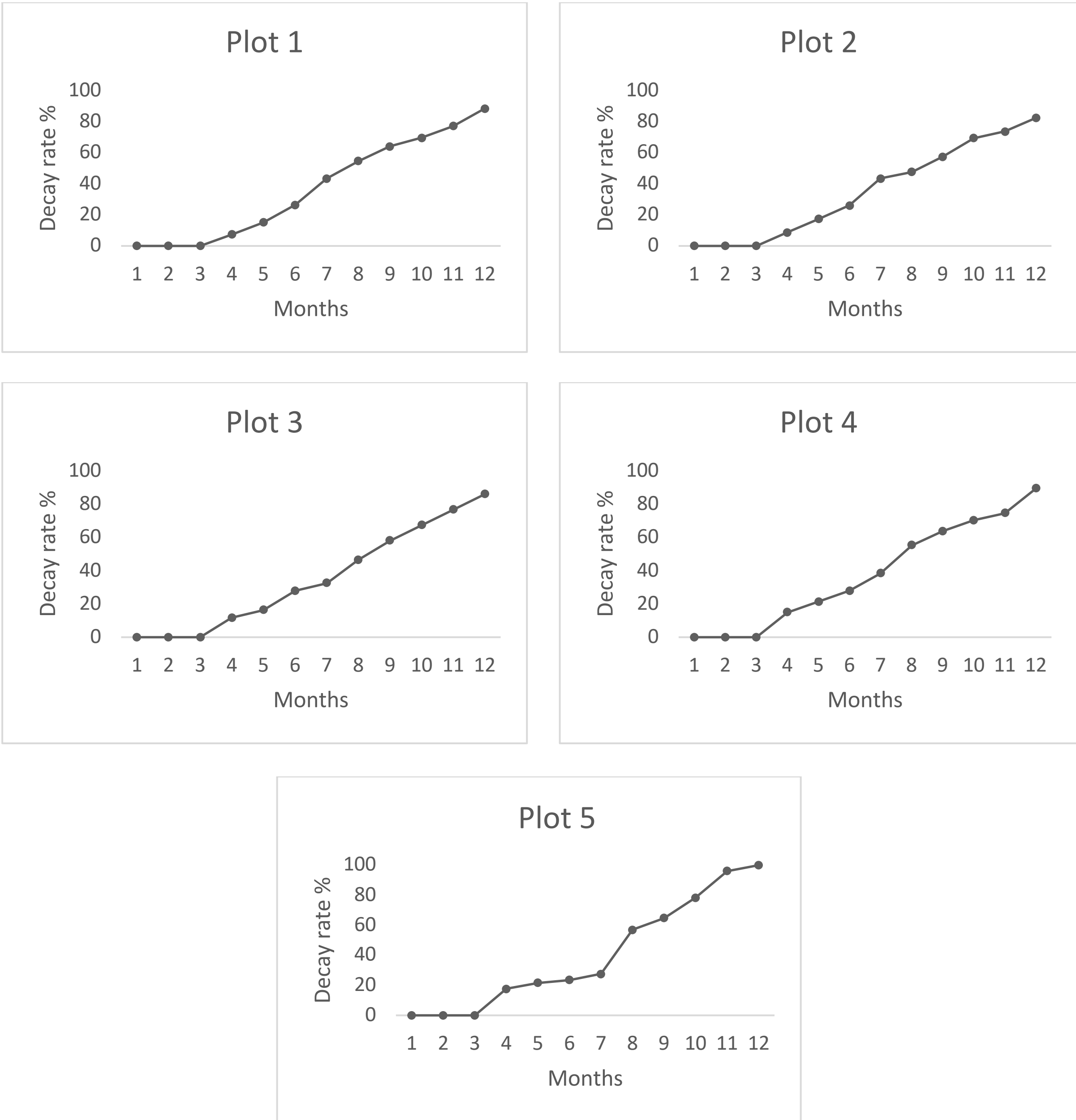


Fig. 5.16. The dung decay rate over a period of 12 months as a percentage of the number of dung pellets remaining on the ground for plots 1 to 5. Plots 1-4 are in rugged habitat, and plot 5 is in sandy habitat

5. 6. Chapter summary

This chaspter has reported the results of fieldwork surveys conducted in 2015 and 2016. Although the 2015 survey enabled a structured survey of a large area and yielded some useful results, it was acknowledged that it was not as effective as had been hoped due to not being linked effectively to the methods for estimating populations. After a further review of the literature, a different approach was adopted for the 2016 field survey. Line transect distance sampling was used to sample indirect signs of Dorcas gazelle and this provided important data, even in circumstances of low density. A total of 250 transects were surveyed covering a total of 500 km. Only 6 groups of gazelle dung pellets were found in the low density stratum and 42 in the high density stratum.

The line transects surveys resulted in an estimated population of 1070 individual Dorcas gazelles. Furthermore, the results show that the Dorcas gazelle is still relatively abundant in some zones of the survey area, especially in Aljasha. This is the first formal population estimate of Dorcas gazelle numbers in this region, but a single survey can never be sufficiently precise to allow absolute confidence in its accuracy. This would require the survey to be repeated in the future using the same survey methodology.

The survey methodology used has demonstrated that, in this terrain, a ground-based approach using distance sampling can be effective in providing high quality information with relatively simple equipment and methods over large areas.

The findings presented in this chapter will be critically discussed in detail in Chapter Seven.

Chapter Six: Genetic diversity of Dorcas gazelle in the study area

6.1. Introduction

This chapter investigates the taxonomic distinctiveness of Dorcas gazelle in the study area. Samples of gazelle DNA were examined to identify the haplotypes and determine if any subspecies exist.

For a number of species of gazelle, conservation efforts are underway, including captive breeding programmes (Mallon and Kingswood, 2001). However, according to Saatoğlu (2015), conservation can be impeded through determining taxonomic classifications on inaccurate morphological assessment, as this leads to the gene pools of different subspecies being mixed together in re-introduction or captive-breeding programmes. Gilbert (2011) noted that Dorcas gazelle are included in European movement restrictions, and she argued that captive populations are therefore vital as “assurance populations” and they can also be used as the basis for reintroduction projects. Assumptions relating to missing pedigree data had not been made for many Middle Eastern animals because of a lack of information on which to base the assumptions. Pedigree completeness for the European Endangered Species Programme (EEP) populations was 100% for Dorcas gazelle. Gilbert (2011) stated that it is vital that sustaining genetic diversity and demographic stability should be the guiding principles in the management of antelope populations.

According to Frankham (2010), species that are endangered usually have a lower degree of genetic variation than those that are not. Gilbert (2011) has argued that losing the genetic variation of a population poses a major hazard for its long-term viability and population size is an important element in assessing the risk of extinction: in general, the larger the population, the better its chance of survival. Reed *et al*. (2003) argued that the minimum size of a population required to ensure its survival depends on its biological features. However, Briscoe *et al*. (1992) have suggested that a large population alone may not be sufficient to preserve genetic variation. After reviewing the research evidence, Gilbert (2011) stated that, for genetic and demographic sustainability, an effective population size (the number of individuals that add offspring) of at least 500 - 5000 is required. This equates to actual population sizes of 1,700 - 20,000. However, the minimum effective number may be different for different species (Miller and Waits, 2003). Franklin (1980) suggested that a minimum, effective number to eliminate the impact of inbreeding in the short term is 50 individuals, with a long-term target of 500 so that mutation can be counter-balanced by drift and evolutionary potential protected.

According to Lerp *et al*. (2011), breeding centres in different countries were helping to preserve the Dorcas gazelle, but they were being impeded by a shortage of phylogenetic and phylogeographic knowledge. They stated that a number of subspecies of Dorcas gazelle had been identified as a result of phenotypic variation. However, the basis for genetic differentiation is generally badly recorded, and there seems to be no apparent ecological or behavioural differentiation to justify the proposed taxonomic classification, as discussed in the literature review. In a summary of their work in the IUCN's newsletter (IUCN, 2012), it was argued that, in this situation for Dorcas gazelle, it is beneficial for managing conservation programmes if a phylogenetic and phylogeographic evaluation of its evolutionary history is undertaken using molecular techniques.

In order to understand the genetic basis and to investigate the genetic diversity of the Dorcas gazelle in the study area, this study used maternally-inherited mtDNA, a marker commonly used in population and conservation studies. According to Saatoğlu (2015), it does not recombine, and the mutation rates for protein-coding mtDNA genes, including Cyt-b, are moderate. He states that this is a particularly useful marker for examining maternal evolutionary history at lower levels of taxonomy, including genera and species and for resolving any uncertainties about taxonomy. Although morphological studies remain common, genetic analysis is being increasingly used by researchers involved in developing strategies for the long-term survival of endangered species using a range of molecular markers (Saatoğlu, 2015). MtDNA studies provide wide opportunities for the identification and differentiation of groups of animals within a species, such as in the field of conservation activities aimed at protecting endangered populations (Perrine *et al*. 2007).

The methods used in this study may have wide applicability for other researchers studying the genetic diversity of animal populations across a range of species. Such an approach may contribute to resolving the dilemma articulated by Senn *et al*. (2014) as to whether local populations of endangered species should be managed discretely to preserve genetic diversity of individual populations or whether they should be managed collectively to reduce the risk of inbreeding.

6.2. Materials and methods

6.2.1. Sample collection

Current advances in molecular genetics have made it possible to extract DNA from faecal samples (Goossens, 2000). The samples (fur and faeces) were collected on an opportunistic basis in order to undertake analyses to help understand the genetic basis of the population in the study area. Faecal samples from Dorcas gazelle were also collected for DNA analysis to provide an important reference set in relation to extant wild stocks in Libya. During fieldwork in 2015 and 2016, a total of 53 dung and tissue samples were collected, 48 from the wild population in the study area south of the Green Mountain area, north east Libya (Fig. 3.1) and 5 from three private farms located in the region of the Green Mountain area, Al Bayda, also in north east Libya, approximately 50 km to the north of the main study area. Some of the samples are shown in Plate 6.1.

Plate 6.1. Samples of Dorcas gazelle (skin/head) from the wild habitat in the study area

Figure. 5.7 on page 109 shows the location of sites where dung samples were collected, and Table 6.1 contains further data relating to the samples. While it is clear that sample sizes are far from ideal, the fact is that Dorcas gazelle is infrequently encountered and consequently sampling was extremely limited in the study area. Tissue samples from carcasses found along transect lines were preserved then refrigerated prior to genomic DNA extraction using high-salt procedures (Sambrook *et al*. 1989). Dung samples were preserved by placing them in sealable plastic bags with small sachets of silica gel (Senn, 2014) which dried out the sample and preserved the DNA. Care was taken not to touch the samples by hand and another plastic bag was used in order not to contaminate the DNA. The date and location were written on the bags or labels and stored away from sunlight prior to DNA extraction.

Figure 6.1 is adapted from Lerp *et al*. (2011) by adding data from this study relating to north east Libya within the red circle. The grey shaded area shows the distribution of Dorcas gazelle based on the IUCN antelope survey reports (Mallon and Kingswood, 2001). For the purpose of this study, the region on the map labelled '*saudiya'* is referred to in the analysis as 'South', in line with the other geographical demarcations in Lerp *et al*. (2011).

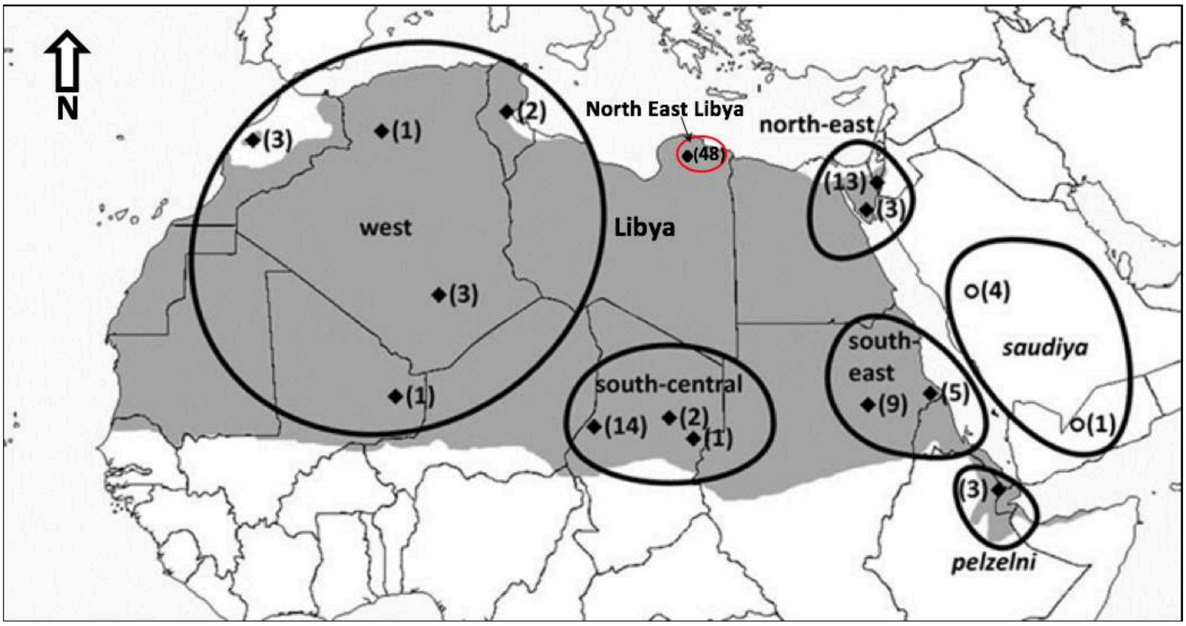


Fig. 6.1. Addition of study area sampling location to Lerp *et al*.'s (2011) map. ♦ = Dorcas gazelle and O = Saudi gazelle. (Numbers in brackets indicate the number of samples obtained, circles indicate 'groups location')

Table 6.1. Origin of wild and captive gazelle samples collected from Libya for use in DNA genetic analysis

Sample name	Genetically confirmed taxon name	Sample type	Origin wild or captive	Year collected	Sample location	Lat./long	Cytochrome b amplification
DRG001	*G. dorcas*	Dried skin	Wild	2015	Aljasha	N 32° 22. 94.2'' E 021° 43' 39.4'' (approx)	+
DRG002	*G. dorcas*	Dried skull	Wild	2015	Aljasha	N 32° 22. 94.2'' E 021° 43' 39.4'' (approx)	+
DRG003	*G. dorcas*	Fresh dung	Captive	2015	Al Bayda	N 32° 47' 81.4'' E 021° 43' 81.9''	+
DRG004	*G. dorcas*	Fresh dung	Captive	2015	Al Bayda	N 32° 47' 81.4'' E 021° 43' 81.9'	-
DRG005	*G. dorcas*	Fresh dung	Captive	2015	Al Bayda	N 32° 47' 81.4'' E 021° 43' 81.9''	-
DRG006	*G. dorcas*	Fresh dung	Captive	2015	Al Bayda	N 32° 46' 04.3'' E 021° 46' 13.0''	+
DRG007	*G. dorcas*	Fresh dung	Captive	2015	Al Bayda	N 32° 46' 04.3'' E 021° 46' 13.0''	-

DRG008	desert hare (*Lepus capensis*)	Fresh dung	Wild	2015	Aljasha	N 32° 22' 92.8'' E 021° 43' 39.3''	+
DRG009	desert hare	Fresh dung	Wild	2015	Aljasha	N 32° 22. 94.2'' E 021° 43' 39.4''	+
DRG010	*G. dorcas*	Skin and skull	Wild	2016	Bulat Mahres	N 32° 02' 26.1'' E 021° 28' 00.1''	+
DRG011	*G. dorcas*	Dried skin	Wild	2016	Bulat Mahres	N 32° 01' 36.7'' E 021° 29' 51.7''	+
DRG012	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 10' 05.4'' E 022° 13' 29.1''	+
DRG013	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 09' 01.9'' E 022° 10' 14.3''	-
DRG014	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 11' 15.7'' E 022° 10' 20.1''	-
DRG015	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 15' 53.1'' E 022° 10' 27.9''	+
DRG016	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 26' 18.9'' E 022° 00' 66.1''	+
DRG017	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 23' 31.5'' E 022° 00' 57.1''	-
DRG018	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 23' 15.7'' E 021° 57' 63.5''	-
DRG019	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22' 50.8'' E 021° 57' 70.8''	-
DRG020	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 21' 28.7'' E 021° 58' 80.0''	+
DRG021	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 20' 41.9'' E 021° 54' 30.6''	+
DRG022	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22' 19.9'' E 021° 52' 11.7''	-
DRG023	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22' 30.3'' E 021° 51' 48.1''	-
DRG024	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 20' 18.8'' E 021° 50' 31.7''	+
DRG025	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 16' 48.4'' E 021° 53' 32.1''	-
DRG026	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 18' 36.7'' E 021° 52' 52.3''	-
DRG027	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 15' 26.6'' E 021° 52' 41.7''	-
DRG028	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 17' 20.6'' E 021° 52' 14.7''	-
DRG029	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 19' 47.9'' E 021° 51' 01.9''	-
DRG030	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 19' 51.2'' E 021° 50' 24.1''	-
DRG031	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 19' 33.9'' E 021° 48' 37.8''	-
DRG032	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 19' 41.9'' E 021° 47' 22.4''	-
DRG033	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 29' 31.3'' E 021° 46' 69.8''	-
DRG034	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 25' 03.8'' E 021° 44' 89.2''	-
DRG035	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 24' 69.1'' E 021° 43' 72.7''	-
DRG036	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 21' 61.6'' E 021° 43' 13.5''	-
DRG037	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 23' 92.3'' E 021° 43' 39.8''	-
DRG038	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22' 92.8'' E 021° 43' 27.3''	-
DRG039	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22' 14.6'' E 021° 56' 66.9''	-
DRG040	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 24' 08.6'' E 021° 47' 1.9''	-

DRG041	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22’ 15.9’’ E 021° 47’ 47.9’’	+
DRG042	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 16’ 45.2’’ E 021° 51’ 12.3’’	-
DRG043	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 14’ 39.1’’ E 021° 52’ 14.4’’	+
DRG044	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 13’ 27.5’’ E 021° 52’ 37.6’’	-
DRG045	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 21’ 21.9’’ E 021° 15’ 33.7’’	-
DRG046	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22’ 13.5’’ E 021° 15’ 53.5’’	-
DRG047	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22’ 55.2’’ E 021° 16’ 73.6’’	+
DRG048	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22’ 11.8’’ E 021° 27’ 55.8’’	-
DRG049	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 22’ 41.2’’ E 021° 25’ 35.3’’	-
DRG050	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 18’ 27.3’’ E 021° 30’ 11.1’’	+
DRG051	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 16’ 21.1’’ E 021° 30’ 44.7’’	-
DRG052	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 15’ 08.7’’ E 021° 30’ 47.7’’	+
DRG053	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 05’ 53.1’’ E 021° 27’ 04.1’’	+
DRG054	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 32° 00’ 42.5’’ E 021° 30’ 51.3’’	+
DRG055	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 31° 19’ 13.3’’ E 021° 32’ 42.9’’	+
DRG056	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 31° 18’ 57.4’’ E 021° 33’ 11.2’’	+
DRG057	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 31° 21’ 42.6’’ E 021° 37’ 12.9’’	-
DRG058	*G. dorcas*	Fresh dung	Wild	2016	Aljasha	N 31° 20’ 07.3’’ E 021° 37’ 37.7’’	-

6.2.2. DNA extraction from collected samples

In 2016 and 2017 the DNA extraction and DNA sequencing of dung and tissue samples were carried out by the researcher with the assistance of the laboratory technicians at the laboratory of the Royal Zoological Society of Scotland in Edinburgh. DNA was extracted from dung using an Isohelix Xtreme kit and from skin tissue biopsies using a DNeasy Blood and Tissue (DNA Sampling and Purification) kit. Standard protocols were followed for each (Isohelix, 2015; Qiagen, 2006).

The DNA extraction from dung took place in a dedicated area. The silica membrane in the Isohelix DNA kit, which uses spin column DNA purification, is designed to isolate highly purified DNA from buccal swabs with minimal losses. A260/280 ratios are typically >1.8 and A260/230 ratios are typically >1.5. After a 30-minute surface wash, the faecal pellet was incubated in a lysis buffer of 0.1 M Tris-HCl-EDTA, 0.01 M NaCl; 1 % N Lauroyl sarcosine at pH 7.5-8.

1.5 ml tubes-label were prepared and 500 μl LYS (Lysis buffer) solution was added to each tube. The faecal pellets were scrubbed with a swab and rinsed using a buffer-snap swab and then placed in the tube (the swab end was up-ended and then briefly centrifuged). The swab was removed and then a 25 μl PK solution-vortex (proteinase K) was added before placing it on a thermoblock at 60˚C for ~1 hr. The 750 μl CB (column binding buffer) was added with buffer-vortex at full speed for 30 seconds, and then 1 ml was transferred to a clean 2 ml tube, and 1 ml ethanol was added and gently mixed.

A 700 μl pipette sample was placed into an Xtreme DNA column-centrifuge on full speed for 1 minute. This was repeated until all of the sample passed through the spin column using a new collection tube each time. 750 μl solution of WB (wash buffer) was added (after checking that the ethanol had been added) then spun at full speed for 1 minute. The washing process was repeated using a new collection tube. The column was transferred into a clean collection tube then centrifuged at full speed for 3 mins to remove all traces of ethanol. Next, the column was placed into a labelled tube and 100 μl of EB (elution buffer) was added (preheated to 70˚C). This was left for 3 minutes at room temperature and then spun for 1 minute at full speed.

For extracting DNA and generating the sequence from the Dorcas gazelle tissues, the same steps were taken as with the DNA extraction from dung, but a different kit was used according to the manufacturer's instructions.

6.2.3. Checking the quality and estimating the quantity of the DNA extracted

The quality and quantity of the isolated DNA samples were checked on a 1% agarose gel prepared with 0.5x of TAE (Tris-Acetate-EDTA) buffer. To be able to visualise the migration of the DNA during electrophoresis, 5 μl of DNA sample was mixed with 5μl of GelRed loading dye and then the dyed sample was run on agarose gels, applying 100 volts for 30 minutes in a horizontal tank containing 0.5x of TAE buffer. The gels were viewed under a UV light using a SYNGENE Ingenius LHR visualising device. An Invitrogen 50 bp DNA ladder was used as a reference for estimation of the sample's DNA concentration. The quality and quantity of each DNA sample were also checked using a NanoDrop 1000 (Thermo Scientific) device. Then dilutions (~50 ng/μl) for each DNA sample were prepared for use in setting up the PCR reactions. Dilutions were conducted to reduce PCR inhibitors in these extractions from faecal samples.

6.2.4. Molecular methods

The gazelle primers GAZ14121_F and GAZ15195_R which were designed from existing sequences on GenBank, were used to amplify the ~597 base pair fragment. A region of the mtDNA including a 597-base pair (bp) fragment in the cytochrome b (Cyt-b) gene was Polymerase Chain Reaction (PCR) amplified using the gazelle primer (GAZ) for forward GAZ14121_F and reverse direction GAZ15195_R (Palumbi, 1996; designed by Senn, 2016), where the base pair was a unit to describe the length of the paired DNA fragment. While the mtDNA control region is more variable than Cyt-b in mammals, this gene was selected because it had been frequently used in the study of gazelle species elsewhere (e.g. Hammond *et al*. 2001; Wronski *et al*. 2010; Wacher *et al*. 2011; Lerp *et al*. 2011 and 2013; Godinho *et al*. 2012; Senn *et al*. 2014) and is a good discriminator at the species level, thus allowing more direct comparisons between different datasets. The general mammalian primers (MCB) for forward MCB398_F and reverse direction MCB869_R (Verma and Singh, 2003; Senn *et al*. 2014) were used where no amplification of Cyt-b was achieved because the animals were not always from the target species (i.e. hares).

PCR amplification of the fragment was conducted with 1 μl of template DNA (10-50 ng ml^{-1}), 2 μl each of forward and reverse primer (10 μM) and 7 μl of Maxima Hot Start PCR Master Mix (Thermo-Fisher). Amplification was performed with an initial denaturation step of 5 minutes at 96˚C, followed by 25 cycles of 1 minute (denaturation) at 96˚C, 1 minute (primer annealing) at 50˚C, 1 minute (elongation) at 60˚C and ending with a 60˚C extension for 10 minutes. Negative controls were always run as standard. Samples that showed reliable amplifications (good amplification and matching genotypes) in this first step were selected to continue the genotyping process.

The fragments were examined by running them out on a 1% agarose GelRed and successfully amplified products were cleaned up by the addition of 0.5 μl of the enzymes EXO1 and 0.5 μl of FastAP (Fisher) with an incubation step of 37˚C for 15 minutes and a denaturation step of 85˚C for 15 minutes.

6.2.5. Cytochrome b sequencing

Cytochrome b sequencing was undertaken by an external company at the University of Edinburgh. PCR reaction volume for the cytochrome b primer was used for amplification. Thermo cycling conditions were set at 95˚C for 5 minutes

[95˚C for 30 seconds, 50˚C for 30 seconds, 72˚C for 60 seconds] for 40 cycles/ 72˚C for 7 minutes. Sequencing was conducted in both forward and reverse direction by adding 8 μl of the BigDye Terminator Kit v3.1 (Applied Bio systems), using 2 μl of PCR product, according to the manufacturer's instructions. Sequences were run on a capillary ABI 3730 DNA Analyser sequencer (Applied Bio systems).

6.2.6. Alignment and editing of sequences

All the 111 Cyt-b sequences (including those from the present study and those taken from the literature) were aligned, edited and analysed using the ClustalW (codons) algorithm in the MEGA7 software (Tamura *et al*. 2013). Primer sequences were trimmed from the alignments. The sequences were translated to verify the absence of stop codons and final corrections were done by eye. Both forward and reverse sequences were aligned for each individual and compared using the MEGA7 software. Any discrepancies were then reassessed. Contig sequences were obtained and then exported in FASTA file format, edited, aligned using the ClustalW Multiple Alignment Tool, and trimmed. Next, the data sequences were exported in nex format. This nex file of data sequences was prepared for further statistical analysis using Population Analysis with Reticulate Trees (PopArt) software (http://popart.otago.ac.nz). To investigate and infer intraspecific phylogenies among the different mitochondrial haplotypes, the Minimum Spanning Network was applied to the Cyt-b datasets for reconstruction of all possible evolutionary pathways among the haplotypes using the software PopArt as shown in Fig. 6.3.

6.2.7. Network building and genetic diversity testing

Haplotype networks for the cytochrome b sequence were created using PopArt software (Leigh and Bryant, 2015, p. 1110). Since this software allows the observation of large data sets from different taxa in the same network, a set of 90 Cyt-b sequences from Dorcas gazelle and different gazelle species were downloaded from the GenBank website (NCBI, 2016). These data sets had been identified in the literature and included those published by Lerp *et al*. (2011) and Godinho *et al*. (2012) covering most of the distribution range of the species around the borders of Libya (including Tunisia, Algeria, Chad, Sudan and Egypt) as an out group. The 21 sequences from the Dorcas gazelle samples originating from the study area in North East Libya were combined with these sequences, making a total of 111 samples which were used in this analysis. The sequences included samples from 69 *Gazella dorcas* (Linnaeus, 1758), 11 *Gazella gazella* (Pallas, 1766), 5 *Gazella leptoceros* (Cuvier, 1842), 3 *Gazella bennettii* (Sykes, 1831) and 2 *Gazella cuvieri* (Ogilby, 1841). GenBank accession numbers are given in Appendix 12. All sequences from the present study begin with the letters DRG. These sequences were trimmed to the 597 bp size applied in this study and then used to estimate genetic diversity parameters and reconstruct a global Median Joining and Minimum Spanning Network. The Network was examined at a number of different probabilities to understand the generated diversity. The analysis was replicated multiple times until stable results were obtained.

Haplotype analysis and the generated diversity statistics were calculated using the PopArt software. To investigate the phylogenetic and geographic relationships among the different mitochondrial haplotypes, the Minimum Spanning Network was applied for the reconstruction of all possible evolutionary pathways using the PopArt software.

Mitochondrial genetic diversity was evaluated using statistics within the PopArt software, both for the whole set of sequences and for each population separately. Several parameters were used, including the number of haplotypes (H), nucleotide diversities (pi), number of segregating sites (Ss), number of parsimony-informative sites (pi-s) and Tajima's D statistic (D).

6.3. Results

6.3.1. DNA extraction and amplification by PCR

All samples from the study area (DRG001 to DRG058) were successfully amplified using the gazelle primers (GAZ14121_F + GAZ15195_R) apart from sample numbers DRG008 and DRG009 (both faecal samples), which did not amplify even after the DNA dilution was increased to 1:50 (1 μl DNA in 49 μl ddH2O). Therefore, those samples were amplified using the general mammalian primer (MCB) in both the forward and reverse directions (MCB398_F + MCB869_R) which resulted in successful amplification. According to the blast results, DRG008 and DRG009 were from *Lepus capensis* (desert hare) (matching with 1% identity), which explained why they did not amplify using the gazelle primer and as a result these samples were excluded from the aligned sequences. Quality control resulted in the exclusion of 37 sequences from further analysis due to the poor quality of the sequencing chromatogram. However, DRG001 to DRG058 were all Dorcas gazelle and 21 out of 58 sequences were suitable for furtherthe analysis.

6.3.2. Cytochrome b gene from mtDNA

The mtDNA Cyt-b fragments of 21 individuals were successfully amplified from the extracted DNA for the samples shown in Table 6.1 A gel image of the amplified mtDNA Cyt-b fragments (50 bp long) including the negative control was clear. As a result, 597 bp long sequences were obtained. Fig. 6.2 shows a part of the aligned sequences that could be observed.

Fig. 6.2. View of 77 bp long part of the aligned sequences. The screenshot was taken from MEGA software version 7. Sequences from DRG001 to DRG021 belong to the gazelles from North East Libya

For this part of the sequences, there was no polymorphism within or between the Dorcas gazelle populations. Furthermore, no polymorphism was found within the 597 bp region, neither within nor between the populations of Dorcas gazelle. However, this species was found to be different at 8 sites out of 597 (8/597). The identity of the individuals for which the sequences were obtained is given in Appendix 13.

6.3.3. Haplotype network construction and genetic diversity

The initial alignment of all sequences produced in this study resulted in a final 597 bp fragment of the mtDNA cytochrome b gene which was used for the analysis of 111 samples (Table 6.2) from eleven distinct populations. These comprised populations representative of the distribution of the Dorcas gazelle within the study area in the North East of Libya, as well as populations from the following countries representing the various regions shown on the map in Fig 6.1: Egypt and Israel (North East), Saudi Arabia and the United Arab Emirates (UEA) (South), Chad (South Central), Sudan (South East) and Tunisia, Mali and Algeria (West).

Representative captive populations held at several protected sites, such as King Khalid Wildlife Research Centre and Al Wabra Wildlife Preservation Qatar, were included. The data also included Pelzelnii Dorcas gazelle, Bennettii gazelle, Cuvieri gazelle and Leptoceros gazelle.

Table 6.2 shows the identical matching sequences and origin of the samples, including whether they are captive or wild. A total of 43 haplotypes were identified with only four of these found in Libyan Dorcas gazelle shared among eleven sites (Fig. 6.3). An additional 4 haplotypes, not recovered in the reference data, were found only in the Libyan samples. This gave a total of 8 haplotypes found within the 21 Libyan samples.

Table 6.2. List of identical sequences created using PopArt software. The table combines data from samples in the literature (Lerp *et al*. 2011 and Godinho *et al*. 2012) with samples from the present study area. N/A = data not available. The data from the Libyan samples (beginning DRG) are shown in the grey shaded areas together with samples from other countries which have the same haplotype. The table excludes samples that have a unique haplotype. This information is shown in diagrammatic form in Fig 6.3

Node label	Matching sequences	Region of origin including country where available (see Fig. 6.3)	Captive/Wild
JN410260 *Gazella gazella*	JN410260 *Gazella gazella*	South	N/A
	JN410352 *Gazella gazella*	South (Saudi Arabia)	N/A
JN410261 *Gazella gazella*	JN410261 *Gazella gazella*	South	N/A
	JN410355 *Gazella gazella*	South	N/A
	JN410356 *Gazella gazella*	South (Saudi Arabia)	N/A
JN410348 *Gazella gazella*	JN410348 *Gazella gazella*	South	N/A
	JN410349 *Gazella gazella*	South	N/A
	JN410350 *Gazella gazella*	South	N/A
	JN410351 *Gazella gazella*	South	N/A
	JN410353 *Gazella gazella*	South (UEA)	Wild
JN410340 *Gazella bennettii*	JN410340 *Gazella bennettii*	*Gazella bennettii* (King Khalid Wildlife Research Centre, Saudi Arabia)	Captive
	JN410357 *Gazella bennettii*	*Gazella bennettii* (King Khalid Wildlife Research Centre, Saudi Arabia)	Captive
JN410259 *Gazella leptoceros*	JN410259 *Gazella leptoceros*	N/A	N/A
	JN410344 *Gazella leptoceros*	West (Tunisia)	Wild
	JN410345 *Gazella leptoceros*	West (Tunisia)	Wild
	JN410346 *Gazella leptoceros*	*Gazella leptoceros* (Western desert, Egypt)	Wild
JF728768 *Gazella dorcas pelzelnii*	JF728768 *Gazella dorcas pelzelnii*	*Pelzelnii*	N/A
	JN410233 *Gazella dorcas*	Captive (Al Wabra Wildlife Preservation, Qatar)	Captive
JN410221 *Gazella dorcas*	JN410221 *Gazella dorcas*	North East (Israel)	Wild
	JN410225 *Gazella dorcas*	North East (Israel)	Wild
	JN410231 *Gazella dorcas*	North East (Israel)	Wild
JN410232 *Gazella dorcas*	JN410232 *Gazella dorcas*	Captive (Al Wabra Wildlife Preservation, Qatar)	Captive
	JN410318 *Gazella dorcas*	Captive (Al Wabra Wildlife Preservation, Qatar)	Captive
	JN410319 Gazella dorcas	Captive (Al Wabra Wildlife Preservation, Qatar)	Captive
JN410219 *Gazella dorcas*	JN410219 *Gazella dorcas*	North East (Israel)	Wild
	JN410222 *Gazella dorcas*	North East (Israel)	Wild

	JN410226 *Gazella dorcas*	North East (Israel)	Wild
	JN410227 *Gazella dorcas*	North East (Israel)	Wild
	JN410228 *Gazella dorcas*	North East (Israel)	Wild
	JN410229 *Gazella dorcas*	North East (Israel)	Wild
	JN410230 *Gazella dorcas*	North East (Israel)	Wild
	JN410245 *Gazella dorcas*	South East (Sudan)	N/A
	JN410250 *Gazella dorcas*	South East (Sudan)	Wild
	JN410251 *Gazella dorcas*	South East (Sudan)	Wild
	JN410316 *Gazella dorcas*	North East (Egypt)	Wild
	JN410333 *Gazella dorcas*	South East (Sudan)	Wild
	JN410334 *Gazella dorcas*	South East (Sudan)	Wild
	KC188752 *Gazella dorcas*	North East (Israel)	Wild
JN410256 *Gazella dorcas*	JN410256 *Gazella dorcas*	West (Mali)	Wild
	JN410338 *Gazella dorcas*	Captive (Al Wabra Wildlife Preservation, Qatar)	Captive
	JN410339 *Gazella dorcas*	Captive (Al Wabra Wildlife Preservation, Qatar)	Captive
	JQ676941 *Gazella dorcas*	West	N/A
	JQ676951 *Gazella dorcas*	West	N/A
	DRG010 *Gazella dorcas*	Libya	Wild
	DRG015 *Gazella dorcas*	Libya	Wild
	DRG050 *Gazella dorcas*	Libya	Wild
	DRG052 *Gazella dorcas*	Libya	Wild
	DRG053 *Gazella dorcas*	Libya	Wild
	DRG012 *Gazella dorcas*	Libya	Wild
JN410241 *Gazella dorcas*	JN410241 *Gazella dorcas*	South Central (Chad)	Wild
	JN410325 *Gazella dorcas*	South Central (Chad)	Wild
	JN410336 *Gazella dorcas*	South East (Sudan)	N/A
	JN410337 *Gazella dorcas*	West (Tunisia)	Wild
	JQ676946 *Gazella dorcas*	West	N/A
	DRG002 *Gazella dorcas*	Libya	Wild
	DRG006 *Gazella dorcas*	Libya	Captive-private farm
	DRG016 *Gazella dorcas*	Libya	Wild
	DRG055 *Gazella dorcas*	Libya	Wild
	DRG056 *Gazella dorcas*	Libya	Wild
JN410234 *Gazella dorcas*	JN410234 *Gazella dorcas*	South Central (Chad)	Wild
	JN410235 *Gazella dorcas*	South Central (Chad)	Wild
	JN410237 *Gazella dorcas*	South Central (Chad)	Wild
	JN410239 *Gazella dorcas*	South Central (Chad)	Wild
	JN410240 *Gazella dorcas*	South Central (Chad)	Wild
	JN410247 *Gazella dorcas*	South East (Sudan)	N/A
	JN410249 *Gazella dorcas*	South East (Sudan)	N/A
	DRG001 *Gazella dorcas*	Libya	Wild
	DRG021 *Gazella dorcas*	Libya	Wild
	DRG024 *Gazella dorcas*	Libya	Wild
	DRG047 *Gazella dorcas*	Libya	Wild
JN410238 *Gazella dorcas*	JN410238 *Gazella dorcas*	South Central (Chad)	Wild
	JN410244 *Gazella dorcas*	South East (Sudan)	Wild
	JN410248 *Gazella dorcas*	South East (Sudan)	Wild
	JN410326 *Gazella dorcas*	South Central (Chad)	Wild
	JN410332 *Gazella dorcas*	South East (Sudan)	Wild
	DRG003 *Gazella dorcas*	Libya	Captive-private farm
	DRG020 *Gazella dorcas*	Libya	Wild
JN410220 *Gazella dorcas*	JN410220 *Gazella dorcas*	North East (Israel)	Wild
	JN410223 *Gazella dorcas*	North East (Israel)	Wild
	JN410315 *Gazella dorcas*	North East (Israel)	Wild
JN410252 *Gazella dorcas*	JN410252 *Gazella dorcas*	West (Algeria)	Wild
	JN410253 *Gazella dorcas*	West (Algeria)	Wild
	JN410254 *Gazella dorcas*	West (Algeria)	Wild

6.3.4. Genetic relationships among species

The differentiation of Libyan Dorcas gazelle populations into eight haplotypes (Table 6.3) was supported by the results from the minimum spanning haplotype network analyses representing the Dorcas gazelle populations from Libya together with gazelles from other localities (Fig. 6.3).

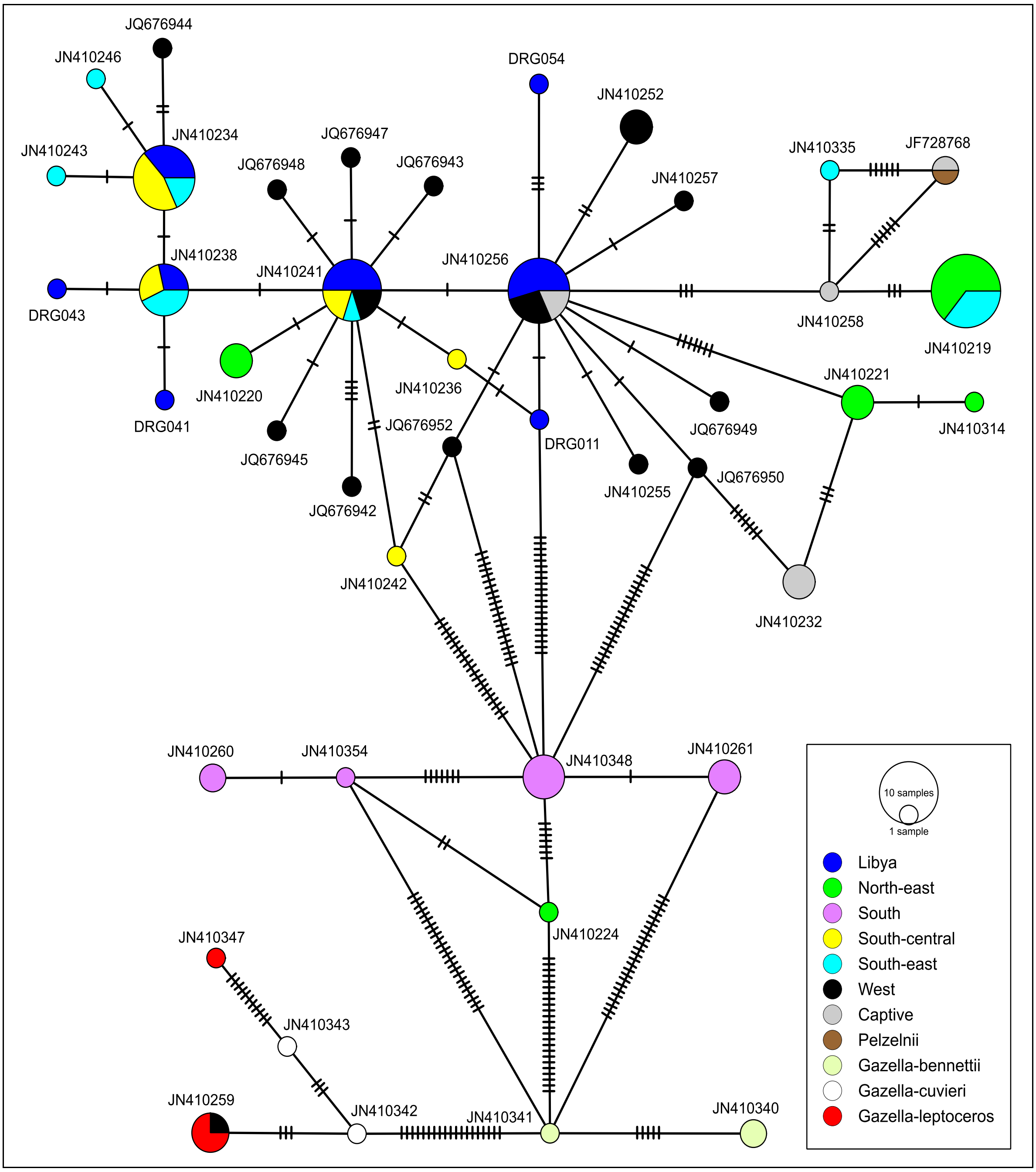


Fig. 6.3. Statistical minimum-spanning network showing the genetic relationships among Dorcas gazelle mtDNA haplotypes from Libya and Dorcas gazelle and other gazelle species from several countries, based on a 597 bp fragment of the mtDNA cytochrome b. Each circle represents a different haplotype and the circle size is proportional to the frequency of the haplotype (number of individuals). The short lines on the connecting lines correspond to one mutational step. All samples are included in this diagram. The GenBank and Libyan samples accession numbers can be found in Table 6.2 and Appendix 12

Table 6.3. The differentiation of the samples of Libyan Dorcas gazelle populations into eight haplotypes

Haplotype	Sample number
Libya 1 (JN410256)	DRG010, DRG015, DRG050, DRG052, DRG053 and DRG012
Libya 2 (JN410241)	DRG002, DRG006, DRG016, DRG055 and DRG056
Libya 3 (JN410234)	DRG001, DRG021, DRG024 and DRG047
Libya 4 (JN410238)	DRG003 and DRG020
Libya 5 (DRG041)	DRG041
Libya 6 (DRG043)	DRG043
Libya 7 (DRG011)	DRG011
Libya 8 (DRG054)	DRG054

The results for identical sequences as shown in Table 6.3 and in the haplotype network in Fig. 6.3, indicate that the Libyan Dorcas gazelle population was divided into eight haplotypes and was closest (same haplotype) to Dorcas gazelle from Mali, Chad, Sudan and Tunisia based on the mitochondrial markers identified in four main clusters. However, haplotypes found in the Libyan Dorcas gazelle group comprise four other distinct lineages:

- The first haplotype group (JN410256) included the wild Dorcas gazelle from Mali (located in western Africa) clustering with two captive animals from Al Wabra Wildlife Preservation, Qatar and two wild samples from western Africa, as well as six wild Dorcas gazelles from Libya.

- The second haplotype group (JN410241) included the wild Dorcas gazelle from Chad (located in South central Africa) clustering with one wild sample from Chad, one sample from Sudan (located in South-East Africa), one wild sample from Tunisia (located in North West Africa), one wild sample from western Africa, as well as one captive and four wild Dorcas gazelle samples from Libya.

- The third haplotype group (JN410234) included the wild Dorcas gazelle sample from Chad, clustering with four wild samples from Chad, two samples from Sudan, as well as four wild Dorcas gazelle samples from Libya.

- The fourth haplotype group (JN410238) included the wild Dorcas gazelle sample from Chad, clustering with one wild sample from Chad, three wild samples from Sudan, as well as one captive and one wild Dorcas gazelle sample from Libya.

There were also four different haplotypes that were distinct from all other samples, but this separation is the result of only one mutational step in the case of the samples DRG041 and DRG043 of Libyan Dorcas gazelle. This compares with the group containing sample JN410238 clustering with six samples which have one haplotype (Fig. 6.3). Sample DRG011 of Libyan Dorcas gazelle has a different haplotype in one mutation compared with the group containing sample JN410256 (Fig. 6.3). In the case of the sample DRG054 the different haplotypes are distinct from a similar group containing sample JN410256, but this separation is the result of three mutational steps (Fig. 6.3), reflecting their uniqueness and low genetic diversity.

No haplotypes were shared between Dorcas gazelles from Israel, Egypt-Sinai (located in North East), Algeria (West) and the Dorcas gazelle samples from Libya. Furthermore, no haplotypes were shared between *Gazella gazella*, *Gazella bennettii* and *Gazella leptoceros* with Dorcas gazelles. Only two samples show a shared haplotype as seen in the group *G. d. pelzelnii* (JF728768) and captive gazelle from Al Wabra Wildlife Preservation, Qatar (Fig. 6.3). It was expected that some samples collected from the southern part of the study area (desert) would belong to the Leptoceros gazelle (assuming the continued existence of this species in Libya) but the results of the haplotypes network (Fig. 6.3) indicated that this was not the case, as no significant relationship was found, and no haplotypes were shared between the gathered samples and wild Leptoceros gazelle from Tunisia and Egypt.

6.3.5. Genetic diversity within species

The overall nucleotide diversity (pi) and number of parsimony-informative sites (pi-s) were 0.0169 and 68, respectively. The diversity estimates within populations are shown in Table 6.4.

Table 6.4. Estimates of genetic diversity for the species of gazelle based on a 597bp mitochondrial fragment

Species	mtDNA					
	N	H	π (pi)	Ss	pi-s	D
All species	111	43	0.0169547	89	68	p (D >= -1.30484) = 0.908243
Libyan Dorcas gazelle	21	8	2.28519	8	4	p (D >= 2036.48) = 0
Gazella dorcas	89	34	0.00815871	56	26	p (D >= -1.82168) = 0.978004
Gazella gazella	11	4	2.7469e+06	9	9	p (D >= 2.24283e+09) = 0
Gazella bennettii	3	2	1.22402e+06	5	0	p (D >= inf) = nan
Gazella leptoceros	5	2	240.829	13	0	p (D >= 167323) = 0
Gazella dorcas pelzelnii	1	1	nan	0	0	p (D >= 0) = 0
Gazella cuvieri	2	2	0.00502513	3	0	p (D >= nan) = nan

N number of samples; H number of haplotypes; π nucleotide diversity; Ss number of segregating sites; pi-s number of parsimony-informative sites; D Tajima's D statistic

Of the 48 samples, genetic analysis indicated that two came from other species (desert hare). Thus, the field identification of dung samples was correct in 95.9% of cases tested.

6.4. Chapter summary

This study fills the gap in knowledge of genetic sequences for specimens of Dorcas gazelle for at least part of Libya and the 21 sequences/8 haplotypes generated represent the first for this region. The genetic analysis of the sampled Dorcas gazelle population from North East Libya found eight haplotypes. They clustered closely with other African Dorcas gazelle populations, with which they shared four haplotypes. However, four specimens from the wild Libyan Dorcas gazelle had no shared haplotypes, either with Dorcas gazelle from other regions of Africa or from other parts of the world, reflecting their uniqueness and higher than expected genetic diversity. From a limited sample, the appreciable levels of mtDNA genetic diversity in the population suggests that there is no major risk of a genetic bottleneck. The population of Dorcas gazelles in Libya constitutes a valuable source of genetic diversity, which is an important factor for future conservation efforts across their global distribution. However, a thorough taxonomic treatment of the Dorcas gazelle using molecular techniques is required for further clarification. In Chapter Seven, these findings will be discussed in relation to the existing literature that was reviewed in Chapter Two.

Chapter Seven: Discussion

7.1. Overview

This chapter critically evaluates the findings that emerged from the literature review and the research results presented in chapters Four, Five and Six, and is summarised in Appendix 14 (summary and critical assessment of the research findings). The combination of the three research methods used in this study has ensured a fuller understanding of the current situation about Dorcas gazelle in the study area, south of the Green Mountain in north east Libya, and some aspects of the study, e.g. the genetic analysis, have contributed to a fuller understanding of its status in North Africa. This chapter brings together the main research outputs under the following themes: (i) current status and population trends, (ii) threats, (iii) genetic status, and (iv) conservation responses. This will enable an examination of the wider picture and provide a link to the proposed strategy for the conservation management of Dorcas gazelle in the study area presented in section 7.6. Section 7.7 discusses how information from this study will be disseminated.

7.2. Current status and population trends

Obtaining up-to-date, accurate information on the distribution and abundance of a species is a necessary first step in any conservation work to ensure that it has a sustainable future. Prior to this study, there was little information about the status of the Dorcas gazelle anywhere in modern Libya. Consequently, little was known about population trends, actual population estimates or current distribution. This study employed an empirical approach to estimate abundance, using standard, well-tried techniques, including questionnaires and field surveys. This is the first study to attempt to assess the abundance of Dorcas gazelle in the wild rather than in protected areas and provides a general understanding of the distribution of the species in the study area and beyond.

The experts surveyed in this study were selected because it was believed that they may have important information that would contribute to answering the research questions. However, the majority of these respondents stated several times that they did not have detailed knowledge of the situation relating to Dorcas gazelle in the study area because they had not worked there and there was very little published information as a result of a lack of local research. Moreover, they stated that no previous quantitative estimate of the abundance of Dorcas gazelle in the study area is available and no systematic surveys had been carried out on which to base any estimates. Although Scholte and Hashim (2013) estimated that the Dorcas gazelle population in Libya is unlikely to exceed 1000 individuals, they do not indicate how they came to that figure. Furthermore, using a distance sampling method, Wacher and Newby (2010) estimated that there are about 8761 individual Dorcas gazelles in a 3300 km^2 study area in Chad. This is a much higher population than was found in the study area of approximately 16,700 km^2 in Libya, but their study provides important information on how such a method can be used. The present study provides the first rigorous assessment of the numbers of Dorcas gazelle in the region and confirms the importance of the study.

There is clear evidence from the local stakeholders of the presence of Dorcas gazelle in and around the study area. This was also confirmed through the sampling of indirect signs in the field survey. In combination with the small number of direct sightings, this method has provided clear evidence of the continued presence of this species in the area, even in circumstances of low density and corroborates the views of local people. Indeed, all the local stakeholder respondents agreed that it is the only type of gazelle to occur in the area, although Khattabi and Mallon (2001) suggested that another type of gazelle, the Leptoceros gazelle, may exist in the desert regions to the south of the study area.

Despite their lack of specific knowledge about the study area, the expert respondents drew attention to indications on social media, that, with increasing poaching, group sizes of Dorcas gazelle tended to be extremely small in comparison with previous data which indicated group sizes of up to one hundred in the 1960s (Hufangl, 1972; Essghaier, 1980; Khattabi and Mallon, 2001). The group sizes of Dorcas gazelle as reported by local stakeholders in the study area during both surveys (2011-5 and 2016) were very small (on average groups of 3 individuals in 2011-5 and 2 individuals in 2016). This was also confirmed during the field survey where gazelle encountered in the study area were in very small groups of about three to four animals on average, but occasionally in pairs, or as single animals.

Collecting data to estimate the abundance of any species, including the Dorcas gazelle, is essential for the effective monitoring of populations. However, estimations of abundance can be controversial due to their potential unreliability and to the difficulty in choosing a method suitable for each situation. This study used two research methods to assess the abundance of Dorcas gazelle in the study area, questionnaire surveys and a field survey. However, there was a 78.3% difference between the estimated population figure obtained through the field survey and the figure reported by the local respondents. The local stakeholders reported sightings of 233 individual Dorcas gazelles in the study area between 2011 and 2016 (Table 4.6), whilst the field survey using distance sampling produced a population estimate of 1070 individual gazelles (in 2016 only). Even this latter figure equates to a density of only 0.07 per km^2 in the study area of approximately 16,700 km^2, which is much lower than the 2-3 per km^2 which was found by Wacher and Newby (2010) in an area of approximately 3,300 km^2 in the Manga region of Chad.

If the population estimate obtained from the field survey proved to be correct, it would indicate this population may be the largest in Libya and be a cause for optimism. It may also be the most genetically viable population in the long term. However, the future of the Dorcas gazelle in the area is not currently assured as no active steps to support it are in place.

It is necessary to consider the discrepancy between the abundance estimates obtained from the questionnaire surveys and from distance sampling, as well as the relative accuracy of each method. As commented above, in Libya, and especially in the study area, there is very limited previous data regarding the size of the Dorcas gazelle population. Acevedo *et al*. (2010) have suggested that, where no information exists about the exact size of the population of a species in a given locality, it is not possible to assess the accuracy of the methods used to assess abundance. In such circumstances, it is only possible to evaluate the methods used in terms of their ability to detect trends in the data.

With regard to the number of gazelle reportedly sighted by the local stakeholder respondents, this may be an over-estimation as it relys on their memory and it is also possible that the same individuals were seen by different people on many different occasions, so are likely to have been double-counted. However, the low number of reported gazelle sightings see to imply that numbers are at a critical level. This coincides with the opinion of the experts, even though they were unable to provide precise estimates.

Previous studies using a distance sampling methodology (e.g. Marques *et al*. 2001) did not use other methods for comparative purposes and consequently the relative reliability of this method cannot be absolutely confirmed. However, the use of this method facilitated the survey of large areas over relatively short periods of time, and it proved to be the most appropriate approach available to obtain data on the structure and distribution of the population based on the literature available at the time.

In this study, the small number of physical sightings of Dorcas gazelle was not sufficient to generate an adequate sample size for analysis using the Distance Sampling software without the inclusion of indirect evidence. Therefore, it was decided to undertake a survey of dung deposits. Abundance estimates derived in this way rely on an analysis of the defecation rate, the density of dung and the rate at which dung decays. Ideally, when using dung deposits to assess abundance, the defecation rate should be estimated for the population under consideration (Marques *et al*. 2001). Swanson *et al*. (2008) stated in their study of wild deer that, although dung is a potential predictor of abundance, the defecation rate of a species in the wild is extremely difficult to measure. It was not possible to measure it in the context and time-frame of the present study. As the defecation rate of Dorcas gazelle in the wild was not known, the defecation rate used in this study was obtained from the literature and was derived from small captive groups of Dorcas gazelle housed at Marwell Zoo in the UK (Cooke *et al*. 2016). This may not accurately reflect the defecation rate of wild animals in the study area as a result of differing diets, habitats, behaviour, etc, and it is a potential source of inaccuracy in the abundance estimates. Nevertheless, the use of a defecation rate from a small captive population may be regarded as an improvement on El-Alqamy's (2003) study which failed to assess defecation rate and it was therefore unable to produce an estimate of the abundance of Dorcas gazelle in Egypt. It does, however, indicate the importance for future studies of attempting to obtain a defecation rate from a wild population. If, in the future, protected areas are established, this may become more achievable, perhaps through direct observation or the use of camera traps.

With regard to the rate at which dung decays, the findings suggest that, within this semi-arid environment, there was little or no decay in the first three months (September to November) and a prominent increase from the fourth month of observation. It must, however, be acknowledged that this study has not been replicated and that diet and the type of terrain may impact on decay rates. Nonetheless, the findings may indicate that the weather has a significant effect on the rate of dung decay, with the winter months having a higher rate compared to other seasons (Swanson *et al*. 2008). Thus, the environmental forces of rain and wind may influence decay. In addition, the type of terrain appeared to affect the decay rate, as plots in the sandy habitat showed faster decay, with 100% of dung disappearing within 12 months compared to those in more rugged areas where only up to 90% disappeared in the same period. In relation to sandy habitats, this is congruent with the findings of El-Alqamy (2003) in Egypt. Mayle *et al*. (1999) suggested that the time for dung to decay is usually shorter in open habitats and especially following heavy rain, or in generally warm, moist conditions. This study showed that the time taken for Dorcas gazelle dung to decay could vary between 120 and 365 days depending on habitat, season and weather.

The detection, probability and encounter rate values obtained from the Distance Sampling software suggested that there should be a high number of gazelle droppings in the study area. However, the total number of dung samples found using this survey method was only 48. Since the survey team was not restricted to certain parts of the study area, observer-induced bias is probably of minor importance (Valente *et al*. 2014).

Abaigar *et al*. (2013) reported that the Dorcas gazelle is able to inhabit a number of differing ecosystems within its range (e.g. barren rocky plateaux, valleys, sandy areas, etc). However, in the study area, the presence and distribution of Dorcas gazelle is significantly influenced by the type of habitat. The main 2016 field survey was targeted using a combination of indigenous and expert knowledge gained from the questionnaires plus an understanding of the area from previous work (Algadafi *et al*. 2007). The number of faecal deposits found in rugged terrain (the high-density stratum) was 42 compared with only 6 in the other, low density stratum. This confirmed the preferred habitats of the Dorcas gazelle indicated by the local stakeholders and conforms with the preferred habitats identified in most other studies (e.g. Hufangl, 1972 and Essghaier, 1980). Most sightings of Dorcas gazelle in the study area as reported by the local stakeholders were around Alkabar (21.9%) and Alhasena (14.6%) in the Aljasha region (the high-density area) (see Fig. 4.3). These results also showed the conformity of the survey design to expectations in terms of stratification and suggest that investing further survey effort in the low-density area would not have been justified (Acevedo *et al*. 2010).

In view of the fact that only 6 piles of dung were detected in the low-density stratum, the analysis of this data set did not yield meaningful results. The habitats and terrain types across the high-density stratum were similar to those in the low-density stratum and therefore the two sets of data were combined and analysed globally. The results of this study suggest that such global analysis can provide useful data. However, in retrospect a combination of this knowledge-based stratification plus a more quantitative habitat-based stratification, such as proposed by Huff *et al*. (2000), would have perhaps given a more targeted approach to this survey. Such an approach could be adopted for improving the efficiency of field data collection in any future studies of the Dorcas gazelle. It is also suggested that a longer-term and wider systematic survey is needed in order to generate sufficient data for more robust estimates of population numbers to be made, both regionally and across Libya.

With regard to the detection function (Fig. 5.15), there were spikes in the probability of detection at 1.5 m, 2.5 m and 4.5 m, with a fall in detection probability at a relatively low distance from the transect line. This was in line with actual observations and the spikes may reflect the focussed attention of both the observer and the recorder at those points in the field survey. According to Focardi *et al*. (2006) and Smith *et al*. (2009), a coefficient of variation (CV) for dung density estimates for stratified analysis by area of approximately 15 to 30 percent can be considered satisfactory. The value of the coefficient of variation (CV) in the present study, as indicated by the Distance software used (MCDS analysis, see Table 5.15), was 27.74%, thus this result corresponds to values of density which indicate optimal fit.

The choice of an indirect method in this study based on a count of pellet groups to estimate Dorcas gazelle abundance by distance sampling appears to have been appropriate. Alves *et al*. (2013) argued that, when considering indirect approaches to obtain ungulate density estimates, line transect distance sampling is the most efficient method. Other authors have also recommended this methodology, arguing that it can determine population size and trends and can be used for conservation purposes (Acevedo *et al*. 2008). Furthermore, according to Valente *et al*. (2014), it is a straightforward method which can provide an indicator of distribution. Results using this method have been found to be reliable in a number of studies, including Marques *et al*. (2001) regarding sika deer (*Cervus nippon*) in Scotland, Focardi *et al*. (2005) regarding roe deer (*Capreolus capreolus italicus*) in Italy, Forsyth *et al*. (2007) regarding red deer (*Cervus elaphus scoticus*) in New Zealand and Wacher and Newby (2010) regarding Dorcas gazelle in Chad. However, Putman *et al*.

(2011) argued against pellet group counts due to their high variance, with up to 95% confidence intervals in density estimates, making them of low informative value and practical use. On the other hand, bias resulting from a breach of distance sampling assumptions will probably be very low when using this method (Valente *et al*. 2014).

The discrepancy between the abundance figure of 1070 individuals obtained from the field survey and the distance sampling calculation, which is high compared to all other information, and the figure of 233 individuals obtained from the responses of local stakeholders may be accounted for by the large size of the study area and the small number of samples obtained. A total of 55 indicators of the presence of Dorcas gazelle (sightings of 4 gazelle groups, 48 dung samples, 2 samples of body tissue and a head) were detected in the surveyed area of 16,700 km^2 along 53 transects totalling 82 km. This is less than the minimum of 60 - 80 samples recommended by Buckland *et al*. (2001) for a robust estimation of density of any type of animal using distance sampling. According to Smith *et al*. (2009), with a small sample size, it is likely to be impossible to achieve the same rigour as with a large sample size. In the future, a greater number of samples should be used to ensure more accurate results. In addition, to the small number of samples, the defecation rate used in the analysis may have been inaccurate, as discussed above. Furthermore, as El-Alqamy and Harwood, (2003) have pointed out, surveys using line transects should be repeated over a number of years because the accuracy of the results increases in line with the number of annual surveys undertaken. According to Valente *et al*. (2014), effective monitoring should be based on long-term studies that are able to detect population fluctuations and to provide stronger inferences. These considerations may account for the discrepancy between the estimates obtained from the two survey methods. However, to understand this inconsistency in more detail, future field surveys should include the collection of a larger number of samples and be conducted over longer periods in suitable habitat areas to facilitate a more valid comparison with other methods.

The results from the questionnaire surveys were based on direct observation by respondents who live in and around the study area as opposed to the indirect observation of dung in the field survey. Moreover, the questionnaire results related to a significantly longer period of time compared with the field survey, which was conducted over a two-month period. However, it is arguable that the respondents underestimated the number of gazelle due to the large size of the study area and its inaccessible, rugged terrain. Castello (2016) has commented that the Dorcas gazelle is a species with very high mobility, which makes it very difficult to count accurately. The continuous, rapid movement of the Dorcas gazelle throughout the area may have contributed to an underestimate of the population by the local stakeholder respondents. Furthermore, the questionairres rely on the respondents' memory of a period of years. For all these reasons, it is considered that the quantitative results relating to population size obtained through the rigorous field survey, which produced a higher estimate, may be more reliable than those obtained through the local stakeholder questionnaires.

According to Witmer (2005), it is very difficult to estimate wildlife populations accurately and it requires high levels of time and resources. Furthermore, Sutherland (2006) argues that there is no ideal method which can give a completely accurate measure of population size. The international experts surveyed in this study agreed with these views. However, despite these caveats, the questionnaire surveys proved to be a useful tool for gathering the views of both international conservation experts and local stakeholders relating to Dorcas gazelle in the past and the present. The field surveys were useful to understand the present activity of Dorcas gazelle, but such surveys do not usually provide information relating to the past. Consequently, the combined use of these two research methods, both of which complement each other, allows greater confidence and has produced estimates which represent the first contemporary information on a wild species in this unprotected region. These methods constitute a foundation for further studies on the distribution and abundance of this gazelle within Libya and provide an insight into potential methods for investigating other species in similar terrain. However, their relative accuracy cannot be assessed since the true population size is unknown in the study area. Consequently, a longer-term more focused future study to estimate the abundance of Dorcas gazelle in the study area is needed to resolve the discrepancy between the abundance estimate obtained from the questionnaire surveys and that obtained through distance sampling. Future surveys are also needed to assess the same areas and transects but perhaps with different survey procedures. It would also be useful to compare results gained from the use of aerial surveys with those obtained from ground surveys.

According to Wacher *et al*. (2015), for species which inhabit large open areas, such as the Dorcas gazelle, the combination of ground and aerial survey may provide the most effective way to count, monitor and assess the conservation status of a species at risk. To facilitate this, the present researcher has retained the exact GPS locations of each transect to enable future comparison (Wanyama *et al*. 2010). Future questionnaire surveys of local stakeholders, including hunters and rangers, would facilitate the on-going collection of monitoring data after a conservation plan has been implemented. Such surveys would help to pin-point areas where Dorcas gazelle have been seen and could also confirm sightings between stakeholders. Stakeholders could also be encouraged to provide information about sightings to a repository for collected data at Omar Al Mukhtar University. Even though this methodology would not provide precise figures, it may provide up-dated data relating to the size of the population and enable trends in the area to be followed over a longer timespan with minimal effort in terms of time, cost and labour.

The local stakeholders who responded to the questionnaires in both 2015 and 2016 were asked if they believed that the Dorcas gazelle had declined in numbers in the study area. They all estimated that the Dorcas gazelle had decreased within a range of 80% to 100% over 5 years. This estimated decline is similar to that reported in the South Sinai region of Egypt in a study by El-Alqamy *et al*. (2011), who observed that the Dorcas gazelle population in that region had declined by 95% in the period 2006 - 2011. It is also compatible with indications in studies by, for example, SCF (2012) that numbers have decreased, although these studies contain no specific population estimates.

If the decline in gazelle numbers indicated by the local stakeholders in the present study was confirmed to be correct, it would suggest that the conservation status of Dorcas gazelle in the study area should be reclassified to '*Critically Endangered*', indicating a population size reduction of >80% or >90% over the preceding 10 years, or three gazelle generations, depending on the method of calculation (IUCN, 2017). However, the Dorcas gazelle is currently classified only as '*Vulnerable*' in its range, although it was found to be '*Endangered*' in Libya in the Global Survey of Antelopes conducted by the Antelope Specialist Group of the IUCN (Mallon and Kingswood, 2001). It is acknowledged that estimating a percentage decline is problematic, but percentage declines are used by the IUCN and many of the studies in this field and so has been retained in this study. The IUCN (2012) define 'high risk of extinction in the wild', as a species with "an observed, estimated, inferred or suspected population size reduction of ≥30% over the last three generations".

The present study also investigated whether the variables of education, age and category of respondent had an effect on various aspects relevant to the study. To the best of the author's knowledge, these variables have never been investigated before in a comparable study. With regard to the frequency with which sightings of gazelle were reported by local stakeholders, education level and category of respondent were found to be statistically significant. The results in relation to level of education are difficult to interpret. In the 2015 survey, more sightings were reported by people who described themselves as 'uneducated' but in 2016 those educated to high school level reported more sightings. It is possible to speculate that people with lower levels of education are less likely to be employed, or they may work outdoors as shepherds or with livestock and may therefore have more opportunities to observe wildlife. Those who identify as hunters in this study hunt simply for sport and are as likely to be educated to university level as any of the other respondents.

The impact of the variables of education, age and category of respondent were also investigated in relation to their estimates of the decrease in the gazelle population. The only variable to be statistically significant, and only in 2015, was age. The highest level of estimated decrease was made by those in the age group 17 - 40 years. It is possible to speculate that this may be because this age group is better informed as a result of access to new technology and social media, as confirmed by the Arab Social Media Report (2017). Whatever the explanation, this finding should not be ignored and merits further investigation.

Finally, data from the questionnaire surveys of local stakeholders also enabled maps of the approximate locations of sightings of Dorcas gazelle and reported hunting incidents in the study area to be created with an adequate degree of accuracy. This data together with these maps will assist in designing an effective conservation programme for Dorcas gazelle in the study area.

7.3. Threats

The opinions of experts and local stakeholders questioned in this study concur with findings reported by SCF (2012; 2015) that the 'Arab Spring', which began in North Africa 2011, led to a massacre of wildlife in all areas and had a particularly negative impact on the Dorcas gazelle in Libya, including the study area. However, the SCF reports provide no specific figures. Zedany and Al-Kich (2013) state that poaching was reasonably well managed by Gaddafi's (prior to 2011) regime but has since risen significantly, although again they produce no statistics. The local stakeholder respondents indicated that overhunting is a major threat that faces the Dorcas gazelle in the study area, and that the recent war in Libya was an equally serious threat.

Conflict and social insecurity are known to accelerate biodiversity declines globally and escalate illegal killing of wildlife (Douglas and Alie, 2014; Gaynor *et al*. 2016) and according to Brito *et al*. (2018), this is likely to increase in the future if action is not taken. The respondents to the expert questionnaire in the present study stated that the situation continued to be very serious and had led to the extermination of entire herds of Dorcas gazelle. They argue that, as a result of indiscriminate hunting for food and trophies, the lack of any central government and the universal availability of firearms, the decline in the population has become much worse over the past four years, although the experts were unable to quantify the decline.

Christy (2015) stated that a quantitative assessment of wildlife threats across the Sahara-Sahel region is problematic. However, there is increasing evidence, e.g. from social media, of the devastation of wildlife as a result of political and social instability (c.f. Zedany and Al-Kich, 2013). Data reported by Brito *et al*. (2018) in relation to Libya as a whole, show that the number of reported Dorcas gazelles illegally killed increased after 2011, with killing events widespread across the country. This is consistent with the results from local stakeholders in the present study relating to the study area, which indicate that the killing of Dorcas gazelle has increased since 2011 (see Fig. 4.8).

The international experts confirmed the view, prevalent in the literature, that poaching is increasing and that hunting from vehicles and the use of automatic rifles now pose the main threats to the Dorcas gazelle throughout its natural range. In Libya, this is exacerbated by the political instability resulting in the poor enforcement of legal protection for the species. Gazelle hunting was restricted and relatively under control during the regime of former Libyan leader Muammar Gaddafi from 1969 to 2011. The authorities regularly carried out campaigns to confiscate conventional hunting rifles from hunters and others. In 1992, the government intervened with plans and programmes to protect wildlife and hunting was banned (Mallon and Kingswood, 2001). Khattabi and Mallon (2001) found that better enforcement of the legislation in the 1990s contributed to some improvement and more game species being observed in several parts of Libya, and those findings conform to the opinions of the local stakeholder respondents in the present study. However, those interventions have not been sustained, and the local stakeholders believed that the conflict in Libya had contributed significantly to the decline in the number of gazelle due to the availability and proliferation of war weapons in addition to conventional hunting rifles. Specifically, the data collected from the in-country questionnaires suggest that illegal killings accelerated one to five years after armed conflicts ignited in Libya (Fig. 4.8). The results of this study show that there was an increase in numbers of gazelle killed during this period. The results also concur with findings from SCF (2012) with regard to enforcement becoming more complicated since the war in Libya in 2011, leading to extremely high numbers of animals having been killed. By contrast, there is some indication from respondents that there was a decline in gazelle killings between 2015 and 2016.

Although the SCF (2015) reported that the large mammal fauna of the Sahara had been declining for around 150 years, they also noted that this decline accelerated with the arrival of powerful modern firearms and 4WD vehicles, and more recently, quad bikes and motorcycles. The motorbike is the principal danger for gazelles even in quite isolated places (SCF, 2012). The ready availability of firearms with a range of up to 2 km enables the hunting of gazelle from long distances and this has led to over-hunting, which was regarded by the local stakeholders as the most probable reason for the decline in wildlife populations, especially the Dorcas gazelle. The use of modern equipment, such as 4×4 vehicles, optical amplifiers and spotlights, which help with night vision, and GPS devices, to identify precise coordinates, facilitates the return of hunters to the location of the gazelle.

Since the war began in 2011, the general public has been able to obtain multiple types of weapons, which has encouraged more people into hunting. However, the local stakeholders did not regard the conflict as the main reason for the decline in numbers of gazelle and they suggested that the deterioration in wildlife populations began before this conflict. They also commented that many hunters of different nationalities crossed the Libyan border illegally up until 2010, traveling to the desert/semi desert areas for the purpose of hunting birds and ungulates, in particular the Dorcas gazelle and the Houbara bustard. The results indicate that hunting decreased in the study area after 2015, perhaps due to increasingly dangerous conditions or decreased numbers of Dorcas gazelle. However, it had already led to the extermination of much wildlife in Libya.

The results of this study indicate that overhunting is the factor with the greatest influence on the rate of decline of the Dorcas gazelle. However, the results of the 2016 survey suggests a decline in the rate of observed killings of Dorcas gazelle (Fig. 4.8), which may indicate that there may be a growing awareness amongst ‘responsible’ hunters of the importance of wildlife for natural areas or maybe it was simply because there are so few animals left to kill. Further investigations are needed to confirm if this trend is continuing and to establish the reasons for it.

This study investigated whether the variables of education, age and category of respondent had an effect on the level at which local stakeholders reported assaults on gazelle. Education level and category of respondent were statistically significant. Those who defined themselves as ‘uneducated’ reported most assaults in both survey years, perhaps because such respondents worked more outside and in agricultural-type jobs, and thus had more opportunities to observe wildlife. It is hardly remarkable that, in both survey years, it was the hunters who reported most assaults on gazelle, although the figure was only statistically significant in 2015. It may be that the correlation did not achieve statistical significance in 2016 because the total number of respondents in all categories reporting attacks was low at only 3% of the total sample, compared with 20.8% in 2015. Furthermore, some respondents may be reluctant to provide such information as it is highly sensitive and may have legal repercussions.

Other threats facing the Dorcas gazelle include a lack of enforcement of the existing wildlife protection laws by government and the non-implementation of penalties which may deter offenders, combined with a general lawlessness. It is not known if the laws were enforced effectively before the recent revolution, but the situation is likely to have deteriorated since then, with the lack of political stability and insecurity. This has contributed to the decline in wildlife generally, and gazelle in particular, and is exacerbated by a lack of protected natural reserves in the study area. As early as 1980, Essghaier reported that the gazelle population was also widely threatened by disturbance from oil drilling activities in Libya. According to Stabach *et al*. (2017), studies have shown that such activities influence the migration of antelope and the way in which they use resources, although they also comment that there are no quantitative estimates of the impact of such activities. However, there is no exploitation of oil in the study area.

A further very significant threat facing the Dorcas gazelle in the study area is a general lack of awareness of the environmental and ecological value of the species. This may imply that there is a direct relationship between the rate of decline of Dorcas gazelle and a lack of awareness of the environmental and ecological value of the species. Zedany and Al-Kich (2013) argue that hunters hunt for sport and pleasure rather than necessity and frequently underestimate the devastation they cause to wildlife. Their view received some confirmation in the present study, where the results showed that all reported attacks on gazelle occurred as a result of 'hobby or entertainment' and 64.6% of local stakeholder respondents disagreed or strongly disagreed with the notion that a main motivation for hunting was the need for bushmeat. 95.4% of local stakeholder respondents agreed or strongly agreed that a lack of environmental awareness of the value of Dorcas gazelle has led to low numbers and the decrease of this gazelle. Therefore, increasing awareness for all members of the community through education programmes may lead to increased protection for the gazelle and this clearly needs to be an element in any effective conservation strategy.

The responses to the questionnaire suggest that wild predators, such as jackals, may not pose a significant threat to Dorcas gazelles in the study area as a result of their low numbers in the area. The nature of the terrain in some places, such as areas with rocky ridges, may also offer a measure of additional protection from such predators, as well as from human predators. 83.8% of local respondents stated that, in the study area, Dorcas gazelle inhabit mostly rugged areas and mountainous terrain. This was previously mentioned by other authors, especially Hufangl (1972), Essghaier (1980) and Khattabi and Mallon (2001). Perhaps this is because, from such terrain, they have a clear view and can more easily detect the presence of predators. Abaigar *et al*. (2013) agree that the gazelles may prefer the security afforded by open areas (plateaux) with high visibility because this provides them with an opportunity to detect predators at sufficient distance to flee. This is in contrast with the findings of Yom-Tov *et al.* (1995), who found that, in Israel, Dorcas gazelle prefer hills, plains or the wide flatlands known as 'Hammada' only at night, whilst wide wadis are preferred during the day. The Dorcas gazelle is a highly gregarious and migratory species, moving long distances in search of safety and good quality browsing. Abaigar *et al*. (2013) argue that the structure of the terrain is a vital factor in ensuring species survival.

There is conflicting evidence about whether the availability of food and water may currently be a limiting factor for the presence of Dorcas gazelle in the study area. A majority of local stakeholders agreed or strongly agreed that a lack of natural habitat to provide food and water have led to low and decreasing numbers of Dorcas gazelle. However, the experts questioned in this study agreed with findings in studies such as SCF (2012) and Wacher and Newby (2012) which make the point that the habitat is still suitable for the Dorcas gazelle across its range and it can coexist with human habitation. The experts indicated that the habitat for Dorcas gazelle remains satisfactory. Although Ghobrial (1974) and Attum and Mahmoud (2012) identified *Acacia* trees as the preferred food of Dorcas gazelle, they do not grow in semi-desert areas such as the study area. The local stakeholders questioned in the present study stated that the species preferred as food by the Dorcas gazelle in the study area are *Capparis spinosa, Rhamnus tripartita, Suaeda mollis, Didymus bipinnatus,* and *Anabasis articulata.* This suggests that it is an adaptable species.

It should be noted that some of these threats are more assumed than proven, or are at least hard to quantify, for example the direct impact of a lack of natural habitat to provide food and water for Dorcas gazelle has not been studied. In addition, these threats are closely linked and overlap with a lack of environmental awareness on the part of Libyan citizens of the value of Dorcas gazelle. Moreover, the hunters questioned in the survey have largely understood the dangers of over- and irresponsible hunting. However, the problem of hunting by people entering into the area remains and should ideally be regulated.

Significantly, the threats to the Dorcas gazelle are likely to act in combination and have a cumulative impact on the species. These impacts may not be evident when examining individual threats separately and may have resulted in only a few small, scattered populations remaining in the wild in Libya.

7.4. Genetic status of Dorcas gazelle in North East Libya

No previous studies have attempted to investigate the genetic profile of Dorcas gazelle in Libya. In this study, the genetic analysis of the sampled Dorcas gazelle population from North East Libya found eight haplotypes (Fig. 6.3). Four clustered closely with other African Dorcas gazelle populations in Mali, Chad, Sudan and Tunisia. This most likely results from the intracontinental translocation of animals (Godinho *et al*. 2012). Overall, the various analyses using mitochondrial DNA samples indicate that the Dorcas gazelle comprise one population (Lerp *et al*. 2011; Godinho *et al*. 2012). However, four specimens from the wild Libyan Dorcas gazelle had no shared haplotypes, either with Dorcas gazelle from other regions of Africa or from other parts of the world, reflecting their uniqueness and higher than expected genetic diversity.

Lerp *et al*. (2011) recommended that ideally sequences from Libya should be included in future analyses, which would have been useful in providing more information on the relationships between the gazelle in the ancient Southern Levant and North Africa (Hadas *et al*. 2015). This study fills this gap in knowledge for at least part of Libya and the 8 haplotypes generated from 21 sequences represent the first genetic data for this region.

The haplotypes found in four of the Libyan Dorcas gazelle (DRG011, DRG041, DRG043 and DRG054) are distinct from the haplotypes found in any other North African Dorcas gazelle. Furthermore, DRG054 is three mutational steps distant from its closest haplotype, JN410256 (Fig. 6.3). This implies the genetic isolation and distinctiveness of the Libyan population, despite its geographic closeness to the Saharan populations. Generally, these unique haplotypes are likely to be the result of hybridisation and mixed ancestry (Hadas *et al*. 2015).

Within this species, a clear geographic structuring of mitochondrial haplotypes was found. The haplotype network showed certain distinct differences between the haplotypes within the population in Libya, compared to the more closely-clustered haplotypes from the wider Saharan populations in Lerp *et al.'s* (2011) study (Fig. 6.3). One of the wild samples from Egypt-Sinai, one captive and four wild samples from Sudan, three samples from Algeria, and all of the samples from Israel had no shared haplotypes with the specimens from Libya (Table 6.2). However, there was a relationship between the haplotype JN410220 comprising Dorcas gazelle samples from Israel and the haplotype JN410241 comprising samples from Libya, Chad, Sudan and Tunisia with a separation of only one mutational step (Fig. 6.3). This study suggests a higher level of genetic differentiation between different groups of Dorcas gazelles than suggested by Lerp *et al*. (2011), who found low genetic differentiation in locations as far apart as Mali and Sinai.

Two samples in the data set, a Pelzelnii gazelle from Qatar, and a captive Dorcas gazelle from Al Wabra Wildlife Preserve, Qatar, both in group JF728768 (*G. d. pelzelnii*), shared a single haplotype (Fig. 6.3), suggesting the Pelzelnii gazelle should be classified as Dorcas gazelle, although further analysis would be required to confirm this. This would be congruent with the findings of Groves (1969), who used now out-dated techniques, and was further supported by Lerp *et al*. (2011), who used network analyses, as in the present study. However, the sample from the Al Wabra Wildlife Preserve was captive (not from the wild), and inferences should be made with caution because captive gazelle may have originated from inbreeding or have been transported from other areas, thus leading to a change in their genetic characteristics. This group shared no haplotypes with the Dorcas gazelles in the Libyan samples, suggesting that *G. d. pelzelnii* does not exist in Libya.

Interestingly, two captive samples from Al Wabra Wildlife Preserve shared a haplotype (JN410256) with six wild samples from Libya, one wild sample from Mali (west) and two unknown samples (west) (Fig. 6.3 and Table 6.2). This suggest that these two captive Dorcas gazelles may have originated in the wild in Libya or Mali.

The haplotype network (Fig. 6.3) notably displays a divergent haplotype (JN410252), which includes three samples of wild Dorcas gazelle from Algeria (West). However, this is inconsistent with the Cyt-b sequences published by Lerp *et al*. (2011) and Godinho *et al*. (2012). Their samples were all collected in Algeria, Tunisia, Mali and Chad and clustered exclusively into two haplotypes. This study indicates that these haplotypes may be more differentiated than Lerp *et al*'s. (2011) study suggested.

No haplotypes were shared between the Libyan Dorcas gazelle samples and the only sample of wild Dorcas gazelle from Sinai in eastern Egypt. However, Frost (2014) suggested that the Dorcas gazelle in the eastern Sahara, western Egypt and eastern Libya are all the same subspecies. As they do not refer to eastern Egypt, this suggests that there may be a difference in subspecies between the gazelles of eastern and western Egypt or that gazelle from eastern Egypt were not sampled.

Several subspecies of Dorcas gazelle have been described on the basis of phenotypic variation by a number of scholars (e.g. by Rostron, 1972; Groves, 1981; Alados, 1987; Yom-Tov *et al*. 1995). However, Mallon and Kingswood (2001), Beudels *et al*. (2006), Lerp *et al*. (2011), Godinho *et al*. (2012) and IUCN (2017) all agree that there is currently no genetic evidence for this clear differentiation between subspecies of Dorcas gazelle. However, despite this, it is noteworthy that they continue to classify Dorcas gazelle in their research according to the identified subspecies. According to the Royal Zoological Society of Scotland (RZSS) and

IUCN Antelope Specialist Group (2014), taxonomic uncertainty is widespread in many types of animals and frequently results from inadequate sampling and the use of historic names for taxa, which often do not flow from rigorous study, but rather from descriptions of individual animals.

From a limited sample, it could be suggested that phenotypic differences may be due to the influence of environmental or climatic factors on the geographical distribution of Dorcas gazelle, with a considerable level of genetic diversity within the species. However, significant further study would be required to confirm these suggestions, which may include sampling of environmental and climatic factors and the GPS tracking of gazelle. Specifically, the appreciable levels of mtDNA genetic diversity in the population found in the present study suggests that there is no major risk of a genetic bottleneck. However, as the haplotype network reveals that the haplotypes of Dorcas gazelle within Libya differ (Fig. 6.3), there may be a genetic explanation for such variations. It seems, therefore, that a thorough taxonomic treatment of the Dorcas gazelle using recent molecular techniques is required for further clarification (Frost, 2014; Castello, 2016).

The results of this study are consistent with Lerp *et al*. (2011) and Godinho *et al*. (2012) in that the combined dataset for Dorcas gazelle shows that this species still has appreciable levels of mtDNA genetic diversity, suggesting that there is currently sufficient genetic diversity in the population. Moreover, the haplotypes of Dorcas gazelle indicate that there is a relationship between clusters of populations from Tunisia and Mali (West), Chad (South Central), Sudan (South East) and Libya. This could mean that there are common ancestral alleles as a result of migration and emigration between populations. Further genetic research is certainly needed to definitively establish the correspondence between the gazelle populations of different locations in Libya and those of other regions in North Africa.

In order to facilitate the implementation of a genetic management programme to maintain levels of genetic diversity, Godinho *et al*. (2012) proposed the establishment of wildlife conservation reserves. Although at present genetic diversity does not seem to be a problem in the Libyan population, this may be helpful to reduce any possible future risk of a genetic bottleneck. Furthermore, as numbers in the population are low, the establishment of a wildlife conservation reserve may also help to increase the effective size of the present population. The implications of such a policy on local stakeholders will be considered in section 7.5.

The results suggest that the Libyan population is of immense significance in global conservation terms, due to there being four haplotypes within the Dorcas gazelle samples which represent a unique genetic diversity that has not been found elsewhere. However, it should be noted that population in other areas have not been well studied using the latest techniques for genetic analysis. The population of Dorcas gazelles in Libya constitutes a valuable source of genetic diversity, which is an important factor for future conservation efforts across their global distribution.

7.5. Conservation measures

It may have been expected that the variables of age, education level and category of respondent would influence attitudes to the effectiveness of current or future conservation measures for Dorcas gazelle in the study area. However, this did not prove to be the case. The responses indicate that there is quite strong agreement, independent of the variables, about the value of a wide range of conservation measures.

The strongest support (100%) among the local stakeholders was for increased protection laws. However, the responses from both the local stakeholders and the experts indicate that it would first be necessary for an effective administration to be in place, able to implement and enforce protection laws and policies. 86.9% of local stakeholder respondents supported a total ban on hunting. They suggested a period of at least five years, but this may be a rather arbitrary length of time (however, five years may be the shortest duration over which legislative systems are capable of effectively operating). The same percentage supported prohibiting hunting during the mating and reproductive season only, which, in Libya, lasts from the beginning of October to the end of April (Hufnagl, 1972). Other measures that had strong support were the enforcement of hunting laws, the imposition of penalties for those who do not obey the hunting laws, and cooperation with global bodies competent in this area. All the above measures would also seem to be acceptable to those respondents who identified as the hunters. However, it should be noted that the hunters in this study were selected through their attendance at a local meeting relating to hunting and conservation and may therefore be more amenable than others to conservation efforts. The sample does not include other hunters who are not interested in conservation, including those, for example, who use 4x4 vehicles and highly destructive weapons. Such hunters may be much less supportive of a hunting ban, but as such these people are extremely difficult to access, thus their views remain largely unknown and in need of further research.

Significant further efforts are required to reduce the number of organised hunting parties which still operate and to ensure that they comply with both the law and sustainable environmental practices. Bro-Jorgensen and Mallon (2016) argue that addressing the growth in hunting with off-road vehicles, quad bikes, and motorbikes is the main priority for the conservation of the species, but they do not suggest how this would be policed.

The current laws regulating gazelle hunting were drafted in Libya as far back as 1951-1969, as discussed in the literature review, and they have never been updated since then. A successful model for the drafting of protection laws in Libya may be found in Tunisia, where a National Strategy for the Conservation and Recovery of Sahelo-Saharan Antelopes and their Habitats 2001-2020 was drawn up in 2000 by the Directorate-General for Forests and the Ministry of Agriculture (IUCN, 2018). This strategy includes a number of legal measures for the protection of wildlife in Tunisia, including some restrictions on hunting in national parks, nature reserves, protected areas and game reserves, and a prohibition on trapping and communication devices. Hunting from vehicles and some firearms (e.g. those with silencers, night-vision scopes, automatic and semi-automatic guns, air rifles and 9 mm carbines) are also banned. Furthermore, the destruction, capture, selling, advertising for sale and purchase of antelopes are prohibited (Republic of Tunisia, 2010). In the light of the Tunisian experience, it is proposed that the Libyan Government's Environmental Commission should include such legal protection in any new constitution that is developed for the country following the recent conflict.

In the current absence of a fully-functioning government and unenforceable legal protection, the potential for local people to act as volunteer protectors, as proposed by some local stakeholders, should be explored. This can be accomplished by monitoring and guarding the species and coordinating the efforts of all the stakeholders involved in the fight against the poaching of the species, with support from members of the Life Organization for Wildlife and Marine Protection. A potential model for the involvement of local volunteers in wildlife protection can be found in the Namibian Volunteer Game Guards scheme. Such volunteers patrol areas to reduce poaching. It has been reported that the scheme has resulted in "a sustained rise in wildlife populations" (WWF, 2014, p. 6). An accreditation scheme under the auspices of the Community-Based Natural Resource Management (CBNRM) strategy has been implemented in Namibia to ensure that volunteer protectors have the appropriate competencies and are adequately trained (Jones, 2012).

Such policies should minimise the risk from hunting and poaching by enforcing the existing protection laws and engaging local communities and stakeholders. Proper understanding of the sanctions provided by the legislation and adequate enforcement may deter illegal hunting. However, currently such legislation is considered to be unenforceable due to the ongoing political instability and this remains a long-term objective. In the short term, protected areas, together with local community engagement in conservation, constitute key tools in securing the survival of wildlife and regional peace and stability at the local level. Although it is not the hunters' task to design a conservation strategy, it is vital to engage them in its implementation and in the promotion and implementation of conservation laws in order to ingrain a culture of environmental responsibility among all stakeholders.

Optimism about the likely success of improved legislative protection was not shared by the experts. Therefore, as a short-term measure, they believed that captive breeding (*in situ* or *ex situ*) may be useful to sustain the Dorcas gazelle population in Libya while waiting for better geopolitical conditions. This view was also shared by the local stakeholders surveyed. Captive breeding programmes have been successful in other places, such as Tunisia (Chammem *et al*. 2008) and Senegal (Abaigar *et al*. 2013; 2018). All experts believed that this would make possible the reintroduction of the species in areas where it has been exterminated. The breeding of Dorcas gazelle from existing captive stock should also form a major element of the conservation strategy (Khattabi and Mallon, 2001).

Both the experts and local stakeholders questioned believed that, in the current situation of unrest and increasing hunting, a captive breeding approach may also be an important method to maintain the Dorcas gazelle in different places in Libya while awaiting better conditions. The IUCN (2002) recommended that threatened taxa of scientific, or cultural importance, and all taxa listed as 'Critically Endangered' and 'Extinct in the Wild' should be subject to intensive *ex situ* management. This can provide an opportunity to genetically and demographically manipulate the population, either globally or locally, to retain or improve genetic diversity (Maunder and Byers, 2005). Captive individuals currently exist in many countries, including

Tunisia and Senegal, which could be used to supplement, or stock, the wild population, for reinforcement, restoration and reintroduction (Pritchard *et al*. 2012). However, the RZSS and IUCN Antelopes Specialist Group (2014) reported that the transfer of captive animals to enhance wild populations may lead to disruption of existing social systems.

A captive breeding programme should be initiated while current wild populations can be maintained *in situ* and before there has been further decline. The establishment of a captive population of Dorcas gazelle would greatly improve the chances of this species' survival and support its long-term persistence. *Ex situ* and *in situ* captive breeding would also assist in the development of husbandry techniques which would be of benefit to the broader recovery efforts. However, there seems to be little possibility of this without outside intervention.

Further research is also required as soon as possible to identify the elements of an effective release programme, although such a programme could not start until hunting has been controlled. According to Hayek *et al*. (2016), the introduction of genetically-suitable captive animals into an existing wild population may increase its viability and thus reduce potential future inbreeding. Although inbreeding is not currently a problem and this study has demonstrated that there is a considerable level of genetic diversity in the study area, should populations decline further, this may well change. Gilbert (2011) has argued that population size is an important element in assessing the risk of extinction: in general, the larger the population, the better its chance of survival. However, Briscoe *et al*. (1992) have suggested that a large population alone may not be sufficient to preserve genetic variation.

An additional benefit that may flow from a release programme is an increase in the number of females in the population. Since the Dorcas gazelle is considered polygamous, an increase of females, and an increased rotation of males between herds, may result in a viable sex-ratio and lead to an increase in the population. Salas *et al*. (2018) have suggested that an appropriate ratio is 5 adult females to 1 adult male. The required elements of a breeding programme for Dorcas gazelle, adapted from Olds (2014), can be found in Appendix 15. However, the implementation of such a programme will clearly only be of value if adequate legal protection is in place.

An example of a captive breeding programme for Dorcas gazelle can be found in SSIG (2002) relating to the Orbata Natural Reserve (ONR) in Tunisia, which is a fenced area created in 1968. The main objective of the ONR is the captive breeding of Dorcas gazelle to reintroduce and reinforce the natural populations in different protected areas across Tunisia. The population rose from 30 animals in the founder population to over 250 individuals by 1982. In October 2001, there were about 200 animals in very good conditions (SSIG, 2002). The only problem seems to be the unbalanced sex-ratio of 2:1 (SSIG, 2002).

A captive breeding programme for Dorcas gazelle was also established in 2002 in Spain by the European Association of Zoos and Aquaria (EAZA) under the auspices of the European Endangered species Programme (EEP). By 2016, the programme had bred 236 individuals which were housed in 12 institutions in Spain, Germany, England and Senegal (Veiga, 2016). The objective of the EEP is to supplement wild populations and bring them up to a sustainable size and to facilitate evolution through natural selection. The programme has already enabled *in situ* reintroduction in Senegal and is considered to be successful (Fernández-Bellon *et al*. 2018), although it seems that precise population figures have not been published.

In Libya, it is necessary to establish groups of Dorcas gazelle in captivity and semi-captivity to ensure a supply for reinforcement and reintroduction projects in the future. In the short term, the El-Kouf National Park (see Fig. 2.2, p. 17), which was home to a small population of Dorcas gazelle before the Libyan conflict, could be developed and used for captive breeding. This should be undertaken and managed by employees/technicians of both the Technical Committee of Wildlife and National Parks and the Ministry of Agriculture, Livestock, and Marine Resources.

Furthermore, an evaluation of current numbers should be undertaken to establish if populations in Egypt, Sudan, Chad, Niger, Algeria and Tunisia are sufficiently large to support the translocation of genetically-suitable individuals, if required, to help conserve the Dorcas gazelle in Libya. Although populations of Dorcas gazelle in the study area can function as sources of genetic variation, this study recommends promoting mutual and continuous gene flow with other wild and captive populations to ensure the long-term survival of this species. The development of metapopulation theory, in conjunction with the development of source-sink dynamics, has emphasised the importance of connectivity between seemingly isolated populations. Although no single population may be able to guarantee the long-term survival of a given species, the combined effect of many populations may be able to do this (Leus *et al*. 2011). A metapopulation approach may be an efficient way to promote gene diversity, as long as no subpopulation becomes extinct and that translocations do not happen too often (Leus *et al*. 2011). Kritzer and Sale (2006) argued against strict application of the metapopulation definitional criteria that extinction risks to local populations must be non-negotiable. In the long-term, when planning cooperative metapopulation breeding, the maintenance of ecological corridors in the study area or in the natural range of gazelle would be useful for the survival of this species (Leus *et al*. 2011).

When the present researcher attended the Sahara Conservation Fund conference in Barcelona in 2016, a member of Tunisia's Wildlife Society suggested supporting Dorcas gazelle populations in Libya by offering a number of their animals if needed (Jebali, 2016). However, if gazelle from outside Libya are introduced, Khattabi and Mallon (2001) state that they should have appropriate genetic characteristics, reflecting the same taxonomic units already present in the country. Data from the present study will help to confirm the genetic suitability of stock for potential introduction. To facilitate a captive breeding programme, it is recommended that an international studbook for Dorcas gazelle is established. At present, a studbook exists only for the subspecies Saharawi Dorcas gazelle (*Gazella dorcas neglecta*) (Abaigar, 2018).

Attum and Mahmoud (2012) have argued that the Dorcas gazelle is an iconic species and it is considered to be “cute” and “attractive”. This may motivate humans to support initiatives to protect the Dorcas gazelle. During the survey period, the researcher received information that a number of local residents have their own private collections of Dorcas gazelles which they use in order to increase the local population through reintroduction and sales. While the number of such animals is unknown, they may contain unique genetic material. However, no further detailed information is currently available, and respondents were not asked directly about this as this information was received after the implementation of the questionnaire. The impact of such private collections needs further investigation.

It is known that captive breeding requires high input of funds and technical manpower in order to achieve satisfactory results (Bro-Jorgensen and Mallon, 2016) as well as inbreeding depression being widely recognised as a problem in captive breeding (Brown and Brown 1998). This suggests that *in situ* conservation of Dorcas gazelle, which still occurs in the study area, albeit in low numbers, could be much more cost effective than *ex situ* conservation. At present, perhaps the best that can be hoped for from a conservation strategy for Dorcas gazelle in the study area is to slow the rate of attrition. The establishment of protected areas is therefore a priority and may be easier to achieve than implementing captive breeding programmes. However, some species are now entirely dependent on captive breeding for their continued survival (IUCN, 2012). In addition, both the experts and local stakeholders when questioned indicated support for starting such programmes for Dorcas gazelle in Libya. Therefore, captive breeding should be part of a conservation strategy.

All of the experts and almost all local stakeholder respondents agreed on the value of protected areas as a conservation measure: 99.2% of local stakeholder respondents saw them as potentially valuable in the present and 100% saw their value for the future. Protected areas are often seen as the flagship or archetypal conservation tool (Sinclair, 2015). According to Bro-Jorgensen and Mallon (2016), protected areas are crucial for antelope conservation, but it depends on the existence of a species. An example of this can be seen in Senegal where a significant effort has been made to recover the Dorcas gazelle, which disappeared from its Sahelian region during the 1970s (Sournia and Dupuy, 1990). The first conservation actions taken were the establishment of two protected areas (the Guembeul Special Fauna Reserve and the North Ferlo Fauna Reserve) in the Sahelian region, where the reintroduction of the population started in 2007, and an environmental awareness programme was implemented (Abaigar *et al*. 2009). According to RZSS and the IUCN Antelopes Specialist Group (2014), protected areas are more cost-effective than reintroduction because, once wild animals have disappeared, it is difficult to bring them back into the wild. As a result, *in situ* conservation efforts through the provision of secure areas, including an increased number of rangers/vehicles/patrols, and raising local awareness should be prioritised. However, wild populations may be still not be viable due to the risk of stochastic events and very small numbers (RZSS and IUCN Antelopes Specialist Group, 2014). In the study area however, despite the estimated population levels being low there appears to be sufficient genetic diversity at present to reduce the risk of dangerously low numbers and sufficient population connectivity to mitigate the effects of any stochastic event.

Protected areas in Libya are the responsibility of the Technical Committee of Wildlife and National Parks. Some reserves and protected areas were established in 1978 in different parts of the country but not in the study area. They were not effectively managed, and the continued financing and implementation of such conservation programmes was made difficult by the fall in global oil prices in 1982 and the imposition of international sanctions on Libya in 1986. Whilst government interventions were useful, their effectiveness was limited by the absence of effective supervision and the lack of technical labour (Algadafi, 2007). Their future effective management will require specialist advice from international organisations such as the Sahara Conservation Fund and the IUCN, as well as from national organisations such as the Libyan Life Organization for Wildlife and Marine Protection and the Libyan Wildlife Trust, which receive funding from the government.

The advantages of establishing protected areas (within the indigenous range of the populations) according to the RZSS and IUCN Antelopes Specialist Group (2014) are to reduce fragmentation and increase metapopulation viability. Dorcas gazelle populations in the study area are currently widely-scattered across rough terrain. The findings presented in this study suggest that providing formal protection for the Dorcas gazelle population is a priority and the objective is to assist the recovery of the existing populations. Initially, the Aljasha area should be declared a sanctuary for the species. This is because the results from the local stakeholders' questionnaires and the field survey demonstrate that this area has a higher number of gazelle compared to the Alsrwal and Albulat areas. A primary conservation management priority should therefore be to conserve and maintain the current gazelle population in the Aljasha area and protect it against invasive activities which may lead to its further decline. Conserving this area is essential for the future spread of gazelles into the adjacent areas of Alsrwal and Albulat areas if conservation action results in the expected future recovery in the size of the population in the study area. At that stage, it will be necessary to extend protected area status to the whole of the study area. Before the establishment of any protected areas, it is important to carefully evaluate the way in which they will impact on local residents as their support will be crucial for success and their efforts to contribute to conservation activities will need to be coordinated.

The experts questioned in this study believed that the habitat remained in a satisfactory condition for Dorcas gazelle throughout its range. However, according to El-Barasi *et al*. (2013, p. 367), the area south of Green Mountain has experienced the "eradication of considerable acreage of plant growth, worsened by recurrent climatic drought". Contrary to the expert respondents, the local stakeholders support the view that there is a lack of natural habitat to provide food and water in the study area. Vegetation may further reduce in the gazelle's preferred habitats if the population size increases. In addition to the negative impacts of poor forage quality on the condition of individual gazelles and especially on pregnant females, their ability to reproduce will also be affected. It can also negatively affect the group size of Dorcas gazelle (Salas *et al*. 2018).

In such circumstances, supplementary feeding may become necessary to help support the population, specifically the provision of water and alfalfa (a favoured fodder crop) at key locations. This may help to minimise mortalities, increase the population size and reduce the need for migration. Supplementary feeding has been used effectively for a range of species in different contexts, e.g. Dutton *et al*. (2015) for wild boar, Senn *et al*. (2014) for dama gazelle and Islam *et al*. (2012) for Arabian oryx (*Oryx leucoryx*). In the Dorcas gazelle conservation projects in Tunisia (Chammem *et al*. 2008) and Senegal (Abaigar *et al*. 2009), the gazelle received complementary barley, corn, peanut straw and alfalfa as well as being supplied with minerals in salt blocks. However, according to Ewen *et al*. (2014, p. 341), "supplementary feeding is often a knee-jerk reaction to population declines, and its application is not critically evaluated". They suggest that, if supplementary feeding is to be used, it should be in a strategic way that can be clearly justified. The potential consequences should be critically evaluated as should "the need, benefit, and risks of food supplementation" (Ewen *et al*. 2014). In other words, this is an emergency measure which needs proper attention to counteract the cause that has made it necessary and ideally the cause should be investigated. The natural breeding of gazelle *in situ* should be closely monitored and, if necessary, conditions should be optimised by the provision of additional food and water in areas where gazelle are found. This may also facilitate the observation and counting of Dorcas gazelle when they are present for feeding.

All of the local stakeholder respondents agreed that more research and monitoring were needed on gazelle in the study area. The collection of data on the Dorcas gazelle is required through the implementation of a system for research and monitoring activities which may cover such matters as the study of habitat use by Dorcas gazelle and monitoring its movements and population dynamics in the study area. Research and monitoring activities have been integrated into conservation programmes elsewhere, for example, in Senegal, the habitat use of captive-born Dorcas gazelle was monitored following their reintroduction to a fenced area (Abaigar *et al.* 2013; 2016) and GPS collars were used to investigate activity patterns within the group (Abaigar *et al.* 2018).

According to the IUCN (2018), establishing a monitoring system involves organising training sessions for staff on census and monitoring methodologies, such as distance sampling, use of camera traps, GPS/radio tracking and genetic identification. A census and evaluation of wild animal populations in the newly-established protected area should be undertaken as soon as practicable, and a monitoring programme should be instigated to determine predation risk for surviving gazelle populations. This aspect of the strategy will require the involvement of the Agricultural and Animal Research Centre and the Ministry of Agriculture, Livestock, and Marine Resources. Furthermore, the local Omar Al Mukhtar University has special expertise and equipment for such activities and should be involved in achieving any research and monitoring programme.

Positive opinions towards Dorcas gazelle may indicate this species has some level of cultural importance and could provide a foothold on which to mount an educational campaign. The results indicate that 98.5% of respondents strongly agreed, or agreed, that communities and hunters needed more information and awareness about the value of the gazelle. 92.3% of experts reported that environmental awareness programmes for local people should be an element of any conservation programme thus stressing the importance of ingraining a culture of environmental responsibility among all stakeholders and fostering environmental awareness to drive societal change. Fernández-Bellon *et al*. (2018) have reported on the success of such actions in Senegal. Education and awareness-raising were also identified by both the experts and local stakeholders as key elements in a long-term wildlife conservation strategy. According to the World Association of Zoos and Aquariums (WAZA, 2006), education is one major element in enhancing the effectiveness of conservation actions and can help to raise the profile of environmental and conservation issues and advocate positive attitudes about, and action for, nature in schools, colleges and universities as well as in the community. Education has been used elsewhere (e.g. Sillero-Zubiri *et al*. 2007) to raise awareness levels and change the attitudes of local communities towards the conservation of wildlife in the long term. Sillero-Zubiri *et al*. (2013) argued that education programmes must be accompanied by effective anti-hunting strategies.

To promote wildlife conservation within the study area, the immediate development of awareness-raising programmes is required, such as those which formed part of the successful Dorcas gazelle reintroduction programme in Senegal (Fernández-Bellon *et al*. 2018) and the conservation programme for Indian gazelle in Rajastan, India (Dookia, 2009). This will involve the creation of suitable awareness-raising materials, organising awareness-raising meetings with hunters and local stakeholders, organising campaigns involving regional and national media (press, TV, radio, etc.), promoting the publication of articles and persuading local people of the importance of volunteering in environmental and conservation projects. In the longer term, wider education programmes, including ones for children, are also necessary to promote country-wide wildlife conservation. In relation to the conservation of the Indian gazelle, Dookia (2009) found that it was vital to teach school children about the importance of wildlife conservation because building awareness from a young age can achieve better results. Wildlife awareness should also form part of the school curriculum. The expert respondents considered that this should be given adequate support as they suggested that children who grow up with a conservation ethic are more likely to assist with conservation efforts. It should focus on the younger members of society, but also educate the older members to change their attitudes toward nature.

According to Anderson and Sprundel (2009, in Sillero-Zubiri *et al*. 2013), an effective wildlife conservation education programme should also take account of levels of illiteracy in the area where it is being implemented by using a range of media and verbal communication strategies. In addition, the potential nomadic lifestyles of the local population should be taken into account. The expressed willingness of the population to participate is also an important factor as proposed solutions to reduce wildlife loss (e.g. public education initiatives and improved husbandry techniques) all, necessarily, directly or indirectly involve local people (Macdonald and Sillero-Zubiri, 2004; Woodroffe *et al*. 2005). For conservation measures to be effective, it will be necessary to empower local communities through such education and awareness programmes. The media can play an important role in this respect and a percentage (20.8%) of local stakeholders seemed to acknowledge the importance of involving the media in the promotion of conservation measures. All Libyan citizens need to be made aware of the value of its wildlife through the use of various media, such as television programmes, posters, seminars, lectures, social media etc. (WAZA, 2006; Sillero-Zubiri *et al*. 2013). There needs to be a well-designed education programme driven by the Technical Committee of Wildlife and National Parks, supported by NGOs and universities, and delivered within local communities.

Generally, the findings of this study and previous literature indicate that a lack of environmental awareness has had a negative effect on Dorcas gazelle populations. This factor is considered an important issue affecting the survival of Dorcas gazelle in the study area because it encompasses and leads to other negative influencing factors. Therefore, if this factor can be addressed and human behaviour towards wildlife improved, it is likely that all other factors contributing to the decline of the Dorcas gazelle will be reduced. This may also lead to an acceptance that hunting should be stopped urgently. This factor has led to the success of the reintroduction project to maintain Dorcas gazelle populations in Senegal and exceeded the objectives (Fernández-Bellon *et al*. 2018). Ingraining a culture of environmental responsibility in citizens and fostering environmental awareness may help to drive societal change and changes in attitude toward nature. Therefore, increasing awareness through education programmes and other actions mentioned above may lead to increased protection for the gazelle in the study area in NE Libya.

The majority of local stakeholders believed that the responsibility for implementing conservation measures rests with the government sector and local communities. This reinforces the importance placed on developing a suitable legislative framework. Furthermore, a high percentage also saw a role for international organisations, perhaps reflecting the respondents' understanding and validation of the expertise and experience of such organisations in promoting conservation. However, the perceived powerlessness of national organisations may account for the very small percentage who believed that responsibility for conservation rests with them. 77% of the experts indicated that it is important to establish political stability, a functioning administration and physical security. Unless Libya can be made to become a functioning state again, there are no opportunities. They saw little chance of this without outside intervention.

Cooperation with international conservation organisations, such as the IUCN, SCF and EEZA-CSIC, is also necessary to promote research, provide training and specialist monitoring, etc., especially while wildlife conservation in Libya is in its early stages. In the long term, external assistance may be helpful, for example, from the Experimental Station for Arid Zones (EEZA-CSIC, Almeria, Spain) and Barcelona Zoo. Conservation programmes instituted by these organisations, such as the Dorcas gazelle reintroduction project in Senegal (Fernández-Bellon *et al*. 2018), have enjoyed considerable success and led to them becoming recognised as world leaders in Sahelo-Saharan conservation, among the conservation community, North African governments and non-governmental stakeholders alike.

It is hoped that this study will enable the development of an integrated programme to maintain Dorcas gazelle populations with the help of a wider range of conservation agencies and the local community.

7.6. A proposed comprehensive conservation management strategy for Dorcas gazelle in the study area in North East Libya

There are a number of programmes for the conservation of Dorcas gazelle in many of the countries in its natural range. The Convention on the Conservation of Migratory Species of Wild Animals (CMS) has funded conservation projects for Sahelo-Saharan antelopes, including the Dorcas gazelle. These projects include establishing a geographical database, information system and a website, and the development of *in situ* conservation and reintroductions in Chad and Senegal (Beudels *et al*. 2006). According to UNEP/CMS (1999), the Libyan Wildlife Technical Committee planned to establish a network of protected areas for wildlife in the south of the country. Despite the original good intentions of the Libyan government, there is still no overall strategy for Dorcas gazelle conservation and none of the proposals above have been implemented so far.

The setting of short-term and long-term priorities is required for the recovery of the Dorcas gazelle in Libya as it remains in decline, even though this study found relative stability in the population in the study area between 2015 and 2016 based on perceptions of local stakeholders. The ongoing decline in the population size of Dorcas gazelle since the 1990s and the increasing pressure from hunting and urbanisation requires urgent attention, as uncontrolled hunting and a lack of awareness of the scale of the problem has already resulted in the reduction of this species, leaving only a few fragmented populations in the wild (Algadafi *et al*. 2017). In the questionnaire survey, the local stakeholders reported 233 sightings of individual Dorcas gazelles in this study. Even in the light of the results of the field survey, which indicate a much higher number of Dorcas gazelle (1070 individuals), it would still be necessary to implement a conservation programme to ensure that it has a sustainable future. In the context of the ongoing conflict in Libya, there is a need for the development of effective policies to reduce the impact of the conflict on wildlife. In view of this, and the threats identified in this study, it is clear that urgent conservation measures are required in order to conserve the Dorcas gazelle in the study area, and to allow it to breed and recolonise parts of its former range, especially in the Alsrwal and Albulat zones of the study area. However, the expense of conservation efforts is likely to increase, or they may even fail, if conflicts continue to escalate.

From the studies on conservation strategies for Dorcas gazelle considered in the literature review and the results of the present study, it can be determined that there are seven main elements for an effective conservation strategy to protect and increase the gazelle population. The IUCN's Conservation Breeding Specialist Group supports an integrated, 'One Plan' approach to conservation planning:

> which considers all populations of the species, inside and outside their natural range, under all conditions of management, engaging all responsible parties and all available resources from the very start of any species conservation planning initiative (Byers *et al*. 2013, p. 2-5).

In this way, they suggest, greater collective outcomes can be achieved, including the bringing together of captive breeding, habitat restoration and reintroduction programmes.

This proposed conservation strategy builds on the experience of a number of existing programmes for the Dorcas gazelle and other species across sub-Saharan Africa, such as the conservation strategies and the recovery of Dorcas gazelle in Tunisia and Senegal which have been successful (SSIG, 2002; Abaigar *et al*. 2018). Another example is the conservation of the Dama gazelle (*Nanger dama*) reported by RZSS and IUCN Antelopes Specialist Group (2014). A further example is the conservation strategy and action plan for Cuvier's gazelle in Morocco, Algeria and Tunisia (IUCN, 2018), which respects the conservation guidelines of the IUCN (IUCN/SSC, 2013). In order to be successful, intervention strategies and objectives need to be established, with short, medium and long-term priorities.

The implementation of any conservation strategy has a range of economic costs, the assessment of which is beyond the scope of this particular study. Rands *et al*.

(2010) argued that the cost of protecting biodiversity is much smaller than its true economic value. As work progresses, the practicalities of implementation (of which cost is one major aspect) will need to be addressed. Some practical examples of how to progress matters have been identified under the various elements of the strategy, but these are only suggestions and precise details will develop from more targeted implementation work following-on from this study. The seven proposed intervention strategies and related activities to assist in the recovery of the Dorcas gazelle in the study area in NE Libya are outlined in Table 7.1.

Table 7.1. A proposed comprehensive conservation management strategy for Dorcas gazelle in the study area in North East Libya. The seven options presented here should be viewed as interdependent and not necessarily mutually exclusive

Conservation Priority	Short-term action	Medium/Long-term action	Practicability
1. Protection laws and enforcement	A total ban on hunting in order to reduce poaching to a minimum. Local community engagement in conservation actions constitutes a key tool in securing the survival of wildlife and regional peace and stability at the local level.	Banning hunting during the mating and reproductive season. The success indicator is an increase in the Dorcas gazelle population. Including wildlife protection in any new constitution.	This element of the strategy cannot be fully achieved until a functioning government and social stability are established. The public are more attracted to nature conservation and the importance of volunteering (charity work) than hunting.
2. Raising awareness	All Libyan citizens need to be made aware of the value of its wildlife, and specifically the Dorcas gazelle by educating them through the use of various mechanisms. Launch awareness-raising campaigns for schools, the media, local communities, journalists, police, the army, hunters and the administrative authorities in order to raise the profile of Dorcas gazelle and its plight. Publish a popular book on Dorcas gazelle, create brochures, postcards, organise conferences, information days, social media campaigns and films.	Wildlife awareness should also form part of the school curriculum.	This element could be achieved in the current circumstances with the support of the local Omar Al Mukhtar University and NGOs.

3. Establishing a protected area	Establish a protected area in Aljasha. Use local volunteers. Improvement of habitats in key areas.	Extend protection to the whole of the study area. Develop management plans for each site (to include a contingency plan to deal with carrying capacity issues).	The protection of Aljasha could be achieved in current circumstances with the support of the local community and NGOs.
4. Research and monitoring	Assess the status of the population and the habitat in Aljasha. Create a programme to estimate numbers of gazelle to be implemented by the local Omar Al Mukhtar University and researchers. Monitoring of diet, diseases and behaviour. Attempt to create metapopulation management for the Dorcas gazelle across the study area to sustain genetic diversity through reducing fragmentation and increasing metapopulation viability.	Investigate potential corridors to ensure the connectivity of the habitat. To be done by the University of Omar Al Mukhtar, the Agricultural and Animal Research Centre, the Ministry of Agriculture, Livestock, and Marine Resources and NGOs. Further research into the viability of a reintroduction and/or reinforcement programme is also required.	This element could be achieved in the current circumstances by building human capacity, increasing the number of staff in various areas and reinforcing material resources.
5. Supplementary feeding	If necessary, conditions should be optimised by the provision of additional food and water in areas where gazelle are found in the study area.	Habitat conditions should be improved where possible.	To be considered after the establishment of a protected area.
6. Captive breeding	The El-Kouf National Park, which was home to a small population of Dorcas gazelle before the Libyan conflict, could be developed and used for captive breeding. Develop best practice husbandry/management guidelines and a suitable sex ratio for a polygamous system. The indicator is clear growth in the population (annual births/deaths). Work with existing local captive collections.	Maximise the effectiveness of captive population management. The suggested programme can be developed and implemented at another places in Libya. Work with organisations with existing collections of captive animals held abroad. Reinforcement of the wild population to be considered alongside captive breeding.	Captive breeding in El-Kouf National Park could be achieved in the current circumstances. This should be undertaken and managed by employees of both the Technical Committee of Wildlife and National Parks, and the Ministry of Agriculture, Livestock, and Marine Resources.
7. International cooperation	Seek advice and financial support from relevant international agencies.	Conduct further research in the study area and across national borders. Develop metapopulation	To be considered after informing relevant local and international

		management strategies with the neighbouring countries of Chad, Sudan, Tunisia, Algeria, Niger and Egypt to coordinate the protection of this species across North Africa and to sustain genetic diversity.	organisations of the proposed conservation strategy.

In the present social and political climate in Libya, it is difficult to imagine how the priorities identified by the experts and local stakeholders could be given practical application on the ground in the study area. However, should the geopolitical situation improve, these matters will need to be taken into account by the government and non-governmental agencies, both domestic and international. These priorities have been taken into consideration in designing the proposed conservation strategy. The main priority of the conservation strategy outlined above is that the Aljasha region of the study area should be declared as a protected area and hunting prohibited in order to safeguard the remaining populations of Dorcas gazelle. One well-managed captive group in the El-Kouf National Park should be established in order to support and strengthen the wild gazelle *in situ*. However, the actions in the proposed programme are not mutually exclusive and may occur simultaneously. For instance, the implementation of protection laws and a semi-captive breeding programme could operate concurrently.

7.7. Dissemination of information

Through the researcher's role as a faculty member at the Omar Al Mukhtar University, this institution will take the lead in promoting this proposed strategy. The proposal will be transmitted to government agencies (the Technical Committee of Wildlife and National Parks, the Ministry of Agriculture, Livestock, and Marine Resources and the Agricultural and Animal Research Centre), NGOs (the Life Organization for Wildlife and Marine Protection and the Libyan Wildlife Trust) and international organisations, such as the IUCN, SCF and EEZA-CSIC, for consultation and comments. Professional links with many of these organisations are already in place. A meeting will then be arranged within the study area to which local stakeholders will be invited to discuss the proposed strategy in detail and to enlist their support in its implementation.

Alongside the dissemination to and through relevant national and international organisations and local stakeholders, the findings of this study will be shared with the academic community through the submission of articles for publication in scholarly journals and attendance at conferences and symposia as well as the publication and distribution of the conservation strategy.

7.8. Chapter summary

The Dorcas gazelle was identified as a key species in need of urgent protection as it is at high risk of extinction in Libya. Hunting during the 2011 - 2016 conflict posed a serious threat to its continued survival in the country. This study provided a preliminary estimation of its abundance in north east Libya, its component genetics and proposed a plan for the protection and recovery of Dorcas gazelle within the study area in North East Libya specifically and Libya more generally. The study used triangulation to assess the current status of the Dorcas gazelle through the combination of questionnaire surveys, field surveys and genetic analyses along with limited existing data. Thus, the data gathered can be used to guide more targeted conservation programmes and future research regarding this endangered species.

As a result, this study provides the first empirical data about abundance and trends in an unprotected area. Two methods (Questionnaire and Distance Sampling) were used to attempt to estimate the abundance of Dorcas gazelle. No previous quantitative estimate of the abundance of Dorcas gazelle in the study area, or in Libya more generally, is available and no systematic surveys had been carried out on which to base any estimates, and therefore its current distribution was unknown. This study confirms the continued presence of the species in the study region up to the summer of 2016.

The results from the survey of local stakeholders and the field survey produced differing estimates of the abundance of the population in the study area, with a 78.3% difference between the estimates obtained using these two methods. The distance sampling results gave a higher estimated population than that reported by the respondents. To understand this inconsistency, future surveys should be conducted to completely validate both methods. Further in-depth research would be highly valuable, perhaps using different assessment procedures, such as the use of aerial surveys in support of ground surveys. Further knowledge of the defecation rate in the wild and of the deterioration rate of dung would help to build confidence in the distance sampling estimates.

This survey of the study area south of Green Mountain in NE Libya indicated that the Dorcas gazelle is still distributed throughout the survey area, but the encounter rate was very low compared to that recorded in previous literature from the 1970s.

The Dorcas gazelle is seriously threatened in Libya with its major threat being overhunting, which may result from a lack of environmental awareness. The population is at real risk of further decline if current illegal hunting continues. Any further decline in its numbers might cause irreversible damage to the population and decrease variability in the genetic pool of the surviving individuals.

A lack of knowledge is a major challenge in promoting the recovery of the Dorcas gazelle, and this may also hinder the ability to assess the true feasibility of the use of various conservation tools. It could be suggested that there is a direct relationship between the rate of decline in the Dorcas gazelle population and a lack of awareness of the environmental and ecological value of the species. Therefore, increasing awareness through education and media programmes may lead to increased protection for the gazelle and this clearly needs to be an element in any effective conservation strategy.

The local stakeholders who responded to the questionnaire estimated the decrease in the wild gazelle population to be in the range of 80% to 100% following the conflict in Libya in 2011. The small numbers indicated by the local stakeholders and its restricted distribution suggest that the classification of Dorcas gazelle should be revised to ‘critically endangered’ in Libya.

The Dorcas gazelle has a low to moderate level of genetic diversity and a medium global genetic structure. The population of Dorcas gazelles in north east Libya constitutes a valuable source of genetic diversity, which is important for future conservation efforts across their global distribution, due to there being four unique haplotypes, a diversity that has not been found elsewhere. Homogeneity across its range means that long-term genetic connectivity has been maintained and that the global population can be considered as a single genetic unit.

This thesis argues that the wild population of Dorcas gazelle in the study area is critically endangered, and is currently not sustainable, especially in the light of continued overhunting. If wild populations are to be at the core of conservation efforts, they need to be self-sustaining. Sustainable management of, and support for, this remaining wild population is required as soon as possible.

If populations become unsustainable in the wild, then attention will need to be directed towards captive and semi-captive breeding programmes to maximise preservation whilst at the same time maintaining the remaining wild populations.

Establishing a captive population is unlikely to put the current wild population at risk. However, a greater understanding of the intricacies of, and capabilities for, the captive breeding of Dorcas gazelle and their reintroduction is necessary to make informed decisions. Methods for, and the usefulness of, captive breeding as an effective conservation tool in north east Libya requires further research.

The wild population in the study area in north east Libya, and indeed the global population, is decreasing. Although the Dorcas gazelle is an adaptable species, with a relatively high reproductive rate, urgent conservation measures need to be taken or the Dorcas gazelle could be lost for ever.

In view of this, and the threats identified in this study, effective conservation measures were explored, and intervention strategies and objectives were established, requiring, short, medium and long-term activities. The enforcement of protected areas, protection laws and engaging local communities and stakeholders, awareness-raising and a captive breeding programme for Dorcas gazelle are considered to be priorities to enable effective decision-making for their recovery. Such conservation actions need to be coordinated to achieve synergy. A holistic approach would best facilitate Dorcas gazelle recovery and would assist should emergency decision-making be required. Therefore, precise details will develop from more targeted implementation work following on from this study.

Chapter Eight: Conclusions and recommendations

8.1. The main conclusions

The research methods used in this study proved to be useful tools for gathering data relating to Dorcas gazelle in the past and the present. The questionnaire surveys enabled an estimate of the size of the population and distribution to be made with limited effort and in a short time with low cost. The distance sampling method of using indirect signs, specifically pellet groups, to estimate Dorcas gazelle abundance appears to be useful approach. The results of this method suggest that analysis using a single global function provides useful data and enabled the first formal population estimates of Dorcas gazelle numbers in the study area to be made with relatively simple equipment and methods and over large areas. In addition, the analysis of maternally-inherited Cyt-b in mtDNA genes conducted in this study has contributed effectively to the current understanding of both the genetic diversity of, and genetic uniqueness within, the Dorcas gazelle population in the study area. The combined use of these three research methods, which all complement each other, allows greater confidence that the outcomes are robust and reliable and facilitates the design of an effective conservation strategy for Dorcas gazelle in the study area.

The three research methods have led to the following main conclusions:

- The results from the survey of international conservation experts showed that no previous quantitative estimate of the abundance of Dorcas gazelle in the study area, or in Libya more generally, was available and no systematic surveys had been carried out on which to base any estimates, and therefore the size of the population and its distribution was unknown. However, based on information from social media, the international conservation experts believed that the number of Dorcas gazelle has decreased in Libya.
- The local stakeholders confirm that this is also the case in the study area. They estimated that there has been an 80% to 100% decrease in the wild gazelle population in the study area since the ongoing conflict began in Libya in 2011. The small number of remaining Dorcas gazelle indicated by the local stakeholders and its restricted distribution suggest that its classification in the study area should be ‘critically endangered’.

- The most important factor that has led to the decline in the number of Dorcas gazelle is overhunting, and this has increased during the ongoing conflict in Libya as result of the proliferation of firearms and the lack of security.
- Overhunting is linked to and overlaps with a lack of environmental awareness, and a lack of appreciation of the value of the Dorcas gazelle on the part of local residents.
- The results from the survey of local stakeholders and the field survey produced differing estimates of the abundance of the population in the study area, with a 78.3% difference between the estimates obtained using these two different methods. The distance sampling results gave a higher estimated population (1070 individuals) than the results from ther questionnaire survey, in which respondents reported seeing 233 individuals. This study therefore confirms the continued presence of the species in the study area up to the summer of 2016, but the encounter rate was very low compared to that recorded in previous literature from the 1970s. Furthermore, it provides the first empirical data on which to attempt to base an estimate of the abundance of Dorcas gazelle in an unprotected area. Irrespective of which estimate is correct, conservation efforts are required to ensure the survival of the species.
- Most reported sightings of Dorcas gazelle in the study area were around Alkabar (21.9%) and Alhasena (14.6%) in the Aljasha region.
- The results of a T-test show that there was no significant difference between the percentage of respondents who reported sightings of gazelle in the period 2011-15 and those who reporting sightings in 2016 (mean = -2.94, SD = 10.53, t = -624, P > 0.566), indicating that there is also likely to be no difference between the number of gazelles in the study area in these two periods.
- The genetic analysis of the sampled Dorcas gazelle population from North East Libya found eight haplotypes. They clustered closely with other African Dorcas gazelle populations, with which they shared four haplotypes. However, four specimens from the wild population had no shared haplotypes, either with Dorcas gazelle from other regions of Africa or from other parts of the world, reflecting their uniqueness and higher than expected genetic diversity. From a limited sample, the appreciable levels of mtDNA genetic diversity in the population suggests that there was no major risk of a genetic bottleneck at the time of the analysis. The population of Dorcas gazelles in NE Libya therefore constitutes a valuable source of genetic

diversity, which is an important factor for future conservation efforts across their global distribution.

- Responses from the questionnaire surveys suggest that the conservation measures most likely to be effective for the recovery of the Dorcas gazelle, and to receive widespread support amongst local stakeholders, include the following: the establishment of protected areas and a captive breeding programme, the enforcement of protection laws, engaging local communities and stakeholders and awareness-raising. Objectives have been proposed, requiring, short, medium and long-term actions. However, precise details will develop from more targeted implementation work following on from this study.

8.2. Review of research aim and objectives

The overarching aim of this study was to develop a strategy for the conservation management of Dorcas gazelle in North East Libya based on an assessment of its current status in the wild and this has been achieved. The following research objectives were identified in relation to each of the initial research questions (Chapter One, section 1.4):

1. To evaluate the current situation relating to the population of Dorcas gazelle in North East Libya, in the area south of Green Mountain, using a combination of questionnaires and field surveys.

As can be seen from the discussion in Chapter Seven, section 7.2 above, this objective was addressed thorough the responses of experts and local stakeholders to questionnaires and the field survey, as well as from the literature review. The results from the local stakeholders and the field survey produced differing estimates of the abundance of the population in the study area. Further refinement of the field survey methodology, especially in relation to the calculation of the defecation rate, is required for this objective to be fully achieved in future studies.

2. To investigate the threats to the population of Dorcas gazelle in North East Libya through the use of questionnaires for different interest groups.

It can be seen from the discussion in Chapter Seven, section 7.3 above that this objective has been achieved. Hunting from vehicles and the widespread use of automatic rifles have been identified as the main threats, and these increased following the start of the conflict in Libya. It has also been demonstrated that there is a lack of awareness and appreciation within the community of the ecological value of the Dorcas gazelle and it could be argued that this leads to overhunting. However, with such a potentially large pool of in-country respondents as a result of the large size of the research area, it is inevitable that the choice of respondents with many differing perspectives will have influenced the outcomes of the survey.

3. To contribute to an understanding of the conservation genetics of Dorcas gazelle in North East Libya through DNA analysis of field samples.

As can be seen from the discussion in Chapter Seven, section 7.4 above, this objective has been fully achieved through the analysis of maternally-inherited Cyt-b in mtDNA genes. This study contributes effectively to current understanding of both the genetic diversity of, and genetic uniqueness within, the Dorcas gazelle population in the study area and beyond.

4. To identify key policy initiatives in the conservation of the Dorcas gazelle in North East Libya by integrating the perspectives of international experts, local stakeholders and existing published data.

The discussion in Chapter Seven, section 7.5 sets out the conservation responses that are likely to be supported by local stakeholders and international conservation experts.

5. To propose a strategy for the conservation of the Dorcas gazelle in the study area by combining the outcomes of the three lines of investigation with existing data.

Based on the responses to the questionnaire surveys and the outcomes of conservation programmes elsewhere, a comprehensive strategy has been proposed for the conservation management of Dorcas gazelle in the study area in North East Libya (Chapter Seven, section 7.6), in fulfilment of the overarching aim of this study. It is hoped that this strategy will be applicable across Libya more generally.

8.3. Limitations of the research

The common research constraints of finance, time and access limited the scope and scale of this study. For example, the number of transect lines in the field survey were limited because of the relatively limited time available for fieldwork. More importantly, the field work was conducted following the events of the 2011 Arab Spring revolution, causing the situation to be unsafe in some areas.

Due to the large size of the research area, it was impossible for the researcher to offer all members in the target population an equal chance to participate in the questionnaire survey. Thus, there was an intrinsic limitation in the sampling method for identifying local stakeholders to respond to the questionnaire. Whilst every effort was made to reduce bias, it cannot be denied that the respondents will each have had a particular perspective that will inevitably influence the outcomes. It also proved impossible to access 'irresponsible' hunters who enter the study area indiscriminately and constitute a threat to the Dorcas gazelle.

A further limitation relates to the approach used in the distance sampling field survey. Literature on this topic (e.g. Buckland *et al*. 2001; Thomas *et al*. 2010; Acevedo *et al*. 2010) recommends the inclusion of three techniques when estimating the abundance of species using dung: counting the dung, length of time to dung decay and defecation rate. This study used the first two techniques, but it was not possible to calculate the defecation rate because of the difficulty in observing individual animals of this species in the study area so a proxy measure was used.

Difficult challenges were faced in data analysis due to the unavailability of published or even unpublished comparative data about Libyan wildlife in general and the Dorcas gazelle in particular to compare with the findings of this study.

Another limitation is that, in relation to genetics, this study analysed only Cyt-b to identify the haplotypes of Dorcas gazelle in the study area from a limited number of samples.

8.4. Recommendations

- Actions must be taken urgently to prevent, or at least reduce, hunting.
- The Libyan Government's Environmental Commission should include legal protection for the wildlife in any new constitution that is developed for the country.
- A new protected area should be established for the formal protection of the population of Dorcas gazelle in the study area. This would enable the species to freely settle, reproduce and allow it to reach population sizes large enough to assure its genetic and ecological viability.
- There was a considerable discrepancy between the estimated population figure obtained through the field survey (distance sampling method) and the number reported by the respondents (questionnaire). To understand this inconsistency, this

research should be replicated, and future surveys should assess the validity of the two methods.

- Future researchers using questionnaire surveys should attempt to obtain a more randomised sample and include those stakeholders who are difficult to access.
- Future studies should attempt to obtain a more exact defecation rate from a wild population, perhaps through direct observation or the use of camera traps. If a protected area is established in the study area, this may become more achievable.
- Suitable monitoring techniques, perhaps combining ground and aerial surveys, should be developed as this would offer the best approach to enumerating, monitoring and assessing the conservation status of the Dorcas gazelle.
- Further detailed study is required into the impact of predators on Dorcas gazelle in the study area as currently little is known.
- Monitoring techniques should be developed to assess the interactions between Dorcas gazelle and livestock and any resulting damage to the habitat.
- The conservation status of the Dorcas gazelle in Libya should be reconsidered and perhaps changed to ‘critically endangered’.
- In relation to genetic analysis, future studies should validate the present findings using other methods of analysis, including microsatellites and mitochondrial control regions. It will be necessary to analyse more samples to get a better picture of this species.
- The small number of individual Dorcas gazelle in the study area should be treated as a single conservation management unit for genetic purposes.
- A global molecular genetics study to evaluate the relationship within and between different populations of Dorcas gazelle is required.
- A greater understanding of the intricacies of, and capabilities for, the captive breeding of Dorcas gazelle and their reintroduction is necessary to make informed decisions. Methods for, and the usefulness of, captive breeding as an effective conservation tool requires further research.
- It will be necessary to design ecological corridors to provide migration opportunities between sub-populations in order to maintain gene flow. Such actions will require cooperation between global wildlife conservation institutions and the Libyan authorities.

- All conservation actions should be coordinated and involve global conservation organisations to achieve synergy and ensure that a holistic approach is adopted. Such an approach would best facilitate recovery and would assist should emergency decision-making be required.

REFERENCES

Abaigar, T. (2018) *Saharawi Dorcas Gazelles (Gazella dorcas neglecta) International Studbook*. [online] [Accessed 20 October 2018] Available at: http://www.eeza.csic.es/documentos/STD_Gazella_dorcas_neglecta_2017.pdf

Abaigar, T., Youm, B., Niaga, M., Ensenyat. C. and Cano, M. (2009) The role of Senegal in the recovery of the Sahelo-Saharan antelope species: the case of the reintroduction of Dorcas Gazelle. *Gnusletter*, **28** (1), pp. 6-8.

Abaigar, T., Cano, M. and Ensenyat. C. (2013) Habitat preference of reintroduced Dorcas gazelle (*Gazelle dorcas neglecta*) in North Ferlo, Senegal: *Journal of Arid Environments***, 97**, pp.176-181.

Abaigar, T., Cano, M., Djigo, A.T. C., Gomis, J., Sarr, T., Youm, B., Fernández-Bellon, H. and Ensenyat, C. (2016) Social organization and demography of reintroduced Dorcas gazelle (*Gazella dorcas neglecta*) in North Ferlo Fauna Reserve, Senegal. *Mammalia*. **10**, pp. 1515.

Abaigar, T., Cano, M. and Ensenyat, C. (2018) Time allocation and patterns of activity of the Dorcas gazelle (*Gazella dorcas*) in a Sahelian habitat. *Mammal Research,* **63**(1), pp. 73-82.

Acevedo, P., Vicente, J., Hofle, U., Cassinello, J., Ruiz-Fons, F. and Gortázar, C. (2007) Estimation of European wild boar relative abundance and aggregation: a novel method in epidemiological risk assessment. *Epidemiology and Infection*, **135**(3), pp. 519-527.

Acevedo, P., Ferreres, J., Jaroso, R., Durán, M., Escudero, A. M., Marco, J. and Gortázar, C. (2010) Estimating roe deer abundance from pellet group counts in Spain: An assessment of methods suitable for Mediterranean woodlands. *Journal of Ecological Indicators*, **10**(6), pp. 1226-1230.

Alados, C. L. (1987) A Cladistic Approach to the Taxonomy of the Dorcas Gazelles. *Israel Journal of Zoology*, **34**(1-2), pp. 33-49.

Algadafi, W. (2007) *Environmental Economic Study for Wildlife Conservation and Development: Case Study for Libyan Gazelle in the South of Aljabal al Akhdar Region*. Masters' Dissertation: Academy of Graduate Studies, Benghazi, Libya.

Algadafi, W., Young, C. H., Besenyei, L., Tobin, C. M. and Ifhima, J. (2017) Status of Dorcas gazelle (*Gazella dorcas*) in the area South of Green Mountain, Libya in 2007: Challenges and Opportunities for the Future. *Animal Research International*, **14**(1), pp. 2676-2682.

Alshalwi, S. (2016) *Wildlife Conservation* [Private conversation]. Al Bayda: Libya, 2 August 2016.

Alves, J., Alves, A., Soares, A. and Fonseca, C. (2013) Pellet group count methods to estimate red deer densities: Precision, potential accuracy and efficiency. *Mammalian Biology*, **78**, 134-141.

Anderson, M. K. (2005) *Tending the wild native American knowledge and the management of California's natural resources*. University of California Press, Berkeley, USA.

Anderson, S. and Sprundel, E. (2009) *Practique pastorales en relation avec l'espace de la reserve naturelle de Termit -Tin Touma, Niger*. Gland: IUCN.

Ankrah, N. A. (2007) *An Investigation into the impact of culture on construction project performance*. Ph.D. Thesis, University of Wolverhampton.

Arab Social Media Report (2017) *Social Media and the Internet of Things.* [online] [Accessed 28 December 2018] Available at: https://www.mbrsg.ae/getattachment/1383b88a-6eb9-476a-bae4-61903688099b/Arab-Social-Media-Report-2017.

Arnold, S. J. (1995) Monitoring quantitative variation and evolution in captive populations. In Ballou, J. D., Gilpin, M., and Foose, T. J. (eds) *Population management for survival and recovery: analytical methods and strategies in small population conservation* pp. 295-317. New York: Columbia University Press.

Attum, O., Eason, P. and Wakefield, S. (2006) Conservation implications of midden selection and use in an endangered gazelle. *Journal of Zoology,* **268(3),** pp. 255-260.

Attum, O. (2007) Can landscape use be among the factors that potentially make some ungulate species more difficult to conserve? *Journal of Arid Environments,* **69**(3), pp. 410-419.

Attum, O., El Noby, S. and Hassan, I. N. (2009) The influence of landscape characteristics and anthropogenic factors on waterhole use by Vulnerable Nubian ibex *Capra nubiana*. *Oryx,* **43**(4), pp. 564-567.

Attum, O. and Mahmoud. T. (2012) Dorcas gazelle and livestock use of trees according to size in a hyper-arid landscape. *Journal of Arid Environments***, 76**, pp. 49-53.

Attum, O., Ghazali, U., EL Noby, S. K. and Hassan, I. N. (2014) The effects of precipitation history on the kilometric index of Dorcas gazelles. *Journal of Arid Environments*, **102**, pp. 113-116.

Aulagnier, S., Cuzin, F., Loggers, C. and Thevenot, M. (2001) Morocco in Mallon, D. P. and Kingswood, S. C. (eds). *Antelopes. Part 4: North Africa, the Middle East, and Asia. Global Survey and Regional Action Plans*. Gland: IUCN. pp. 13-21.

Awami, A. M. (1997) *Libyan wild animals (in Arabic).* Al-Bayda: Omar Al- Mukhtar University publications.

Baharav, D. (1980) Habitat utilization of the Dorcas gazelle in a desert saline area. *Journal of Arid Environments*, **3**, pp. 161-167.

Baharav, D. (1982) Desert habitat partitioning by Dorcas gazelle. *Journal of Arid Environments*, **5**, pp. 323-335.

Ballou, J. D., Lees, C., Faust, L. J., Long, S., Lynch, C., Bingaman Lackey, L. and Foose, T. J. (2010) Demographic and genetic management of captive populations. In Kleiman, D. G., Thompson, K. V., and Kirk Baer. C (eds) *Wild mammals in captivity: principles and techniques for zoo management*, Chicago: University of Chicago Press, pp. 219-252.

Baldus, R. D. (2009) *Wild Heart of Africa: The Selous Game Reserve in Tanzania*. Johannesburg: Roland Ward Publications.

Balmford, A., Mace, G. M. and Leader-Williams, N. (1996) Designing the ark: Setting priorities for captive breeding. *Conservation Biology*, **10**(3), pp. 719-727.

Barnes, R. and Jenssen, K. (1987) How to count elephants in forests. *IUCN African Elephant and Rhino Specialist Group Technical Bulletin*, **1**, pp. 1-6.

Barnes, R., Blom, A., Alers, M. and Barnes, K. L. (1995) An estimate of the numbers of forest elephants in Gabon. *Journal of Tropical Ecology*, **11**, 27-37.

Bernard, R. (2006) *Research Methods in Anthropology: qualitative and quantitative methods* (4th ed.). Altamira Press, New York, USA.

Bernard, R. (2011) *Research methods in anthropology qualitative and quantitative approaches* (5th ed.). Altamira Press, Plymouth, UK.

Beudels, R. C., Devillers, P, R. Lafontaine, M, Devillers-Terschuren, J. and Beudels, M. O. (eds) (2006) *SaheloSaharan Antelopes. Status and Perspectives: Report on the conservation status of the six Sahelo-Saharan Antelopes*. Bonn: UNEP/CMS.

Briscoe, D. A., Malpica, J. M., Robertson, A., Smith, G. J., Frankham, R., Banks, R. G. and Barker, J. S. F. (1992) Rapid Loss of Genetic-Variation in Large Captive

Populations of Drosophila Flies - Implications for the Genetic Management of Captive Populations. *Conservation Biology*, **6**(3), pp. 416-425.

Brito, C. J., Durant, M. S., Pettorelli, N., Newby, J., Canney, S., Algadafi, W., Rabeil, T., Crochet, P., Pleguezuelos, M. J., Wacher, T., Smet, K.,Gonçalves, V. D., Silva, J. F. M., Martínez-Freiría, F., Abáigar, T., Campos, C. J., Comizzoli, P., Fahd, S., Fellous, A., Garba, H. M. H., Hamidou. D., Harouna, A., Hatcha, H. M., Nagy, A., Silva, L. T., Sow, S. A., Vale, G. C., Boratyński, Z., Rebelo, H.and Carvalho. B. S. (2018) Armed conflicts and wildlife decline: Challenges and recommendations for effective conservation policy in the Sahara-Sahel. *Conservation Letters*. DOI: 10.1111/conl.12446.

Bro-Jorgensen, J. and Mallon, D. P. (eds) (2016) *Antelope Conservation: From Diagnosis to Action*. Chichester: John Wiley and Sons.

Brown, J. L. and Brown, E. R. (1998) Are inbred offspring less fit? Survival in a natural population of Mexican jays. *Behavioral Ecology*, **9**, 60-63.

Bryman, A. (2006) Paradigm peace and the implications for quality. *International Journal of Social Research Methodology*, **9**(2),111-126.

Bruner, A. G., Gullison, R. E., Rice, R. E. and Fonseca, G. A. B. (2001) Effectiveness of parks in protecting tropical biodiversity. *Science*, **291**(5501), pp. 125-128.

Buckland, S. T., Anderson, D. A., Burnham, K. P. and Laake, J. L. (1993) *Distance Sampling: Estimating Abundance of Biological Populations*. London: Chapman and Hall.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. and Thomas, L. (2001) *Introduction to Distance Sampling*. Oxford: Oxford University Press.

Buckland, S. T., Anderson, D. R., Burnham K. P., Laake, J. L., Borchers, D. L. and Thomas, L. (eds) (2004) *Advanced Distance Sampling*. Oxford: Oxford University Press.

Byers, O., Lees, C., Wilcken, J. and Schwitzer, C. (2013) The One Plan Approach: the philosophy and implementation of CBSG's approach to integrated species conservation planning. *WAZA Magazine*, **14**, pp. 2-5.

Caro, T. (2003) Umbrella species: critique and lessons from East Africa. *Animal Conservation Forum*, **6**(2), pp. 171-181.

Cassini, M. H. and Galante, M. L. (1992) Foraging under predation risk in the wild guinea pig – the effect of vegetation height on habitat utilization. *Annales Zoologici Fennici*, **29**, 285-290.

Castello, R. J. (2016) *BOVIDS of the World: Antelopes, Gazelles, Cattle, Goats, Sheep, and Relatives*. Princeton: Princeton University Press.

Caughley, G. (1980) *Analysis of Vertebrate Populations*, Chichester: John Wiley and Sons.

Convention on Biological Diversity (CBD) (2010) *Strategic Plan for Biodiversity 2011-2020: Further information related to the technical rationale for the Aichi Biodiversity Targets, including potential indicators and milestones*. [online]. [Accessed 11 April 2015]. Available at: https://www.cbd.int/doc/meetings/cop/cop-10/information/cop-10-inf-12-rev1-en.pdf.

Chammem, M., Selmi, S., Nouira, S. and Khorchani, T. (2008) Factors affecting the distribution of Dorcas gazelle: *Journal of Zoology*, **275**(2), pp. 146-152.

Chape, S., Spalding, M. and Jenkins, M. (2008) *The World's Protected Areas: Status, Values and Prospects in the 21st Century*. Berkeley: University of California Press.

Christy, B. (2015) How killing elephants finances terror in Africa. *National Geographic Magazine*, Retrieved from www.national geographic.com/tracking-ivory/article.html.

Central Intelligence Agency (CIA) (2016) *The Word Factbook* [online]. [Accessed 13 August 2016]. Available at: <https://www.cia.gov/library/publications/resources/theworldfactbook/geos/ly.html>.

Cooke, R. S., Woodfine, T. Petretto, M. and Ezard T. H. G. (2016) Resource partitioning between ungulate populations in arid environments. *Ecology Evoluation*, **6**(17), pp. 6354-6365.

Collis, J. and Hussey, R. (2003) *Business research: A practical guide for undergraduate and postgraduate students*. 2nd edition. MacMillan, Basingstoke.

Conover, M. (2002) *Resolving human-wildlife conflicts. The science of wildlife damage management*. Lewis publishers. ACRC press company, Boca Raton.

Crandall, G. S., Ohayon, L. J., Wit, de. Luz A., Hammond.E. J., Melanson, L. K., Moritsch, M. M., Davenport, R., Ruiz, D., Keitt, B., Holmes, D. N., Packard, G. H., Bury, J., Gilbert, S. G. and Parke, M. I. (2018) Best practices: social research methods to inform biological conservation. *Australasian Journal of Environmental Management*, **25**(1), 6-23.

Cuzin, F. (2003) Les grands mammifères du Maroc méridional (Haut Atlas, Anti Atlas et Sahara): Distribution, Ecologie et Conservation. Ph.D. Thesis, Laboratoire de Biogéographie et Ecologie des Vertèbrés, Ecole Pratique des Hautes Etudes, Université Montpellier II.

Dawson, T. P., Jackson, S. T., House, J. I., Prentice, I. C. and Mace, G. M. (2011) Beyond Predictions: Biodiversity Conservation in a Changing Climate. *Science*, **332**(6025), pp. 53-58.

Denscombe, M. (2008) Communities of practice: a research paradigm for the mixed methods approach. *Journal of Mixed Methods Research*, **2**(3), 270-83.

Denzin, N. K. (2010) Moments, mixed methods, and paradigm dialogs. *Qualitative Inquiry*, **16**, 419-427. http://dx.doi.org/10.1177/1077800410364608.

Derrick, B., Broad, A., Toher, D. and White, P. (2017) "The impact of an extreme observation in a paired sample design". *Metodološki zvezki - Advances in Methodology and Statistics*, **14**(2), 1-17.

Dick, D. M. and Hines, E. M. (2011) Using distance sampling techniques to estimate bottlenose dolphin (*Tursiops truncatus*) abundance at Turneffe Atoll, Belize. *Marine Mammal Science*, **27**, 606-621.

Dittrich, L. (1968) Keeping and breeding gazelles at Hannover Zoo. *International Zoo Yearbook*. **8**(1), pp. 139-143.

Dittrich, L. (1972) Gestation periods and age of sexual maturity of some African antelopes. *International Zoo Yearbook*. **12**(1), pp. 184-187.

Dookia, S. (2009) *Conservation of Indian Gazelle or Chinkara through community support in Thar Desert of Rajasthan, India: Project Technical Report.* [online] [Accessed 12 May 2017] Available at: https://www.rufford.org/files/SM_Sumit%20Dookia%20Detailed%20Final%20Report.pdf.

Douglas, L. R. and Alie, K. (2014) High-value natural resources: Linking wildlife conservation to international conflict, insecurity, and development concerns. *Biological Conservation*, **171**, 270-277.

Durant, S., Wacher, T., Bashir, S., Woodroffe, R. and Ornellas, P. (2014) Fiddling in biodiversity hotspots while deserts burn? Collapse of the Sahara's megafauna. *Diversity and Distributions*, **20**(1), pp. 114-122.

Dutton, J. S., Clayton, H. T. and Evans, S. M. (2015) *The social aspects of wild boar in the Forest of Dean*. Unpublished report for the Forestry Commission by the University of Worcester. [online] [Accessed 13 August 2018] Available at: https://www.worcester.ac.uk/documents/FCProjectFinalReport2.pdf.

East, R. (1988) *Antelopes. Global survey and regional action plans. Part 1*. East and Northeast Africa. Gland, IUCN.

East, R. (1992) Conservation status of antelopes in North Africa. *Species*, **18**, pp. 35-36.

East, R. (1999) *African Antelope Database 1998: Occasional paper of the IUCN Species Survival Commission No. 21.* Gland*:* IUCN.

Eggert, L. S., Eggert, J. A. and Woodruff, D. S. (2003) Estimating population sizes for elusive animals: the forest elephants of Kakum National Park, Ghana. *Molecular Ecology,* **12**(6) pp. 1389-1402.

El-Alqamy, H., Wacher, T., Hammada, A. and Taema, M. (2001) Distance sampling for estimating density and abundance of Dorcas gazelle (*Gazella dorcas*) in and around St. Katherine Protectorate, south Sinai, Egypt, *First International Conference on Distance Sampling* 30 July - 3 August. University of St. Andrews: ICODS.

El-Alqamy, H. (2003) *Developing and Assessing Population Monitoring Program for Dorcas gazelle (Gazella dorcas*) *Using Distance Sampling in Southern Sinai, Egypt.* MPhil Thesis. University of St Andrews.

El-Alqamy, H. and Harwood, J. (2003) Evaluating the power of time of series of line transect surveys to detect change in populations of Dorcas gazelle (*Gazella dorcas*) in south Sinal Egypt: *CBD Technical Series,* **9**, pp. 27-29.

El-Alqamy, H. and Baha El Din, S. (2006) Contemporary status and distribution of gazelle species (*Gazella dorcas* and *Gazella leptoceros*) in Egypt. *Zoology in the Middle East*, **39**(1), pp. 5-16.

El-Alqamy, H., Ismael, A., Abdel H. A. and Nagy, A. (2011) *Decline of Dorcas Gazelle in South Sinai-Egypt* [online] [Accessed 4 April 2015] Available at: https://www.researchgate.net/publication/263467187_Decline_of_the_Dorcas_gazelles_in_Sinai_Egypt.

El-Barasi, M. Y., Barrani, M. W. and Al Tajoury, O. R. (2013) Land Deterioration of a Semi-Desert Grazing Area in the North-Eastern Zone of Libya (Cyrenaica). *Journal of Environmental Science and Engineering* **2**(6B), pp. 357-373.

Emre Can, O., D'Cruz, N., Garshelis, D. L., Beecham, J. and Macdonald, D. W. (2014) Resolving human-bear conflict: a global survey of countries, experts, and key factors. *Conservation Letters,* **7**(6), pp. 501–513.

Environmental Systems Research Institute (ESRI) (2017) *ArcGIS* [online] [Accessed 3 March 2017] Availabe at: <http://www.esri.com/arcgis/about-arcgis>.

Essghaier, M. F. A. (1980) A Plea for Libya's Gazelles. *Oryx***. 15**(14), pp. 384-385.

Essghaier, M. F. A. and Johnson, D. R. (1981) Distribution and use of dung heaps by Dorcas gazelle, *Gazella dorcas*, in western Libya. *Mammalia***, 45**(2), pp. 153-156.

Essghaier, M. F. A., Taboni, I. M. and Etayeb, K. S. (2015) The diversity of wild animals at Fezzan Province (Libya). *Biodiversity Journal*, **6**(1), pp. 245-252.

Etikan, I., Abubakar, M. and Alkassim, R. S. (2016) Comparison of Convenience and Purposive Sampling. *American Journal of Theoretical and Applied Statistics.* **5**(1) pp. 1-4.

Ewen, J. G., Walker, L., Canessa, S. and Groombridge, J. J. (2014) Improving supplementary feeding in species conservation. *Conservation Biology*, **29**(2) pp. 341-349.

Fadem, B. (2008) *High-Yield Behavioral Science*. High-Yield Series. Hagerstown, MD: Lippincott Williams and Wilkins.

Feilzer, M. Y. (2010) Doing Mixed Methods Research Pragmatically: Implications for the Rediscovery of Pragmatism as a Research Paradigm. *Journal of Mixed Methods Research* **4**(1), pp. 6-16.

Fernández-Bellon, H., Enseñat, C., Cano, M. and Abáigar, T. (2018) Reaching beyond the objectives of a Dorcas gazelle reintroduction project. *EAZA Conservarion Forum*, 22-25 May 2018.

Fewster, R. M., Buckland, S. T., Burnham, K. P., Borchers, D. L., Jupp, P. E., Laake, J. L. and Thomas, L. (2009) Estimating the encounter rate variance in distance sampling. *Biometrics*, **65**(1), pp. 225-236.

Focardi, S., Isotti, R. and Tinelli, A. (2002) Line transect estimates of ungulate populations in a Mediterranean forest. *Journal of Wildlife Management*, **66**(1), pp. 48-58.

Focardi, S., Montanaro, P., Isotti, R., Ronchi, F. and Scacco, M. (2005) Distance sampling effectively monitored a declining population of Italian roe deer *Capreolus capreolus italicus*. *Oryx*, **39**, 421-428.

Focardi, S., Aragno, P., Montanaro, P. and Riga, F. (2006) Inter-specific competition from fallow deer *Dama dama* reduces habitat quality for the Italian roe deer *Capreolus capreolus italicus*. *Ecography*, **3**, 407-418.

Ford. A. T., Fryxell, J. M. and Sinclair, A. R. E. (2016) Conservation Challenges facing African Savanna Ecosystems. In Bro-Jorgensen, J. and Mallon, D. P. (eds) (2016) *Antelope Conservation: From Diagnosis to Action*. Chichester: John Wiley and Sons.

Forsyth, D. M., Barker, R. J., Morriss, G. and Scroggie, M. P. (2007) Modeling the relationship between fecal pellet indices and deer density. *Journal of Wildl Manage*, **71**, 964-970.

Frankham, R. (2010) Challenges and opportunities of genetic approaches to biological conservation. *Biological Conservation*, **143**, 1919-1927.

Franklin, I. R. (1980) Evolutionary change in small populations. *Conservation Biology: an evolutionary-ecological perspective* (eds M. E. Soulé and B. A. Wilcox), pp. 135-149. Sinauer Associates, Sunderland, Massachusetts.

Frost, W. (2014) *The Antelope of Africa*. Johannesburg: Jacana Media.

Gaynor, K. M., Fiorella, K. J., Gregory, G. H., Kurz, D. J., Seto, K. L., Withey, L. S. and Brashares, J. S. (2016) War and wildlife: Linking armed conflict to conservation. *Frontiers in Ecology and the Environment*, **14**, 533-542.

Geldmann. J., Barnes, M., Coad, L., Craigie, I. D., Hockings, M, and Burgess, N. D. (2013) Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. *Biological Conservation*, **161**(5), 230-238.

Gentry, A. W. (1964) Skull characters of *Gazella dorcas*. *Annual Magazine of Natural History*, **13**, p. 353.

Ghobrial, L. I. (1974) Water relation and requirement of the Dorcas gazelle in the Sudan. *Mammalia*, **38**(1) pp, 88-108.

Gilbert, T. (2011) *The sustainability of endangered species under intensive management: the case of the scimitar-horned oryx (Oryx dammah)*. PhD Thesis. University of Southampton.

Gil-Sánchez, J. M., Herrera-Sánchez, F.J., Álvarez, B., Arredondo, Á., Bautista, J., Cancio, I., Castillo, S., Díaz-Portero, M.Á., de Lucas, J., McCain, E. and Pérez, J. (2017) Evaluating methods for surveying the Endangered Cuvier's gazelle (*Gazella cuvieri*) in arid landscapes. *Oryx*, **51(4)**, pp, 648-655.

Goossens, B., Chikhi, L., Utami, S. S., de Ruiter, J. and Bruford, M. W. (2000) A multi-samples and multi-extracts approach for microsatellite analysis of faecal samples in an arboreal ape. *Conservation Genetics*, **1**, 157-162.

Goddard, J. (1967) The validity of censusing black rhinoceros' populations from the air, East African. *Wildlife Journal*, **5**(1), pp, 18-23.

Godinho, R., Abaigar, T., Lopes, S., Essalhi, A., Ouragh, L., Cano, M. and Ferrand, N. (2012) Conservation genetics of the endangered Dorcas gazelle (*Gazella dorcas spp*.) in North western Africa. *Conservation Genetics,* **13**(4), pp.1003-1015.

Gordon, I. J. (1991) Ungulate re-introductions: the case of the scimitar-horned oryx. *Symposia of the Zoological Society of London,* **62**, pp. 217-240.

Gorman, E. and Clayton, P. (2005) *Qualitative research for the information professional: A practical handbook*. 2nd edition, Facet Publishing, London.

Gray, D. (2004) *Doing research in the real world*. London: Sage Publications.

Grettenberger, J. F. (1987) Ecology of the Dorcas gazelle in northern Niger. *Mammalia,* **51**(4), pp. 527-536.

Groves, C. P. (1969) On the smaller gazelles of the genus *Gazella* de Blainville, 1816. *Zeitschrift für Säugetierkunde*, **34**(1), pp. 38-60.

Groves, C. P. (1981) Notes on gazelles. 3. The Dorcas gazelles of north Africa. *Anali Museo Civicio di Storia Naturale di Genova*, **83**, pp. 455-471.

Gusset, M. and Dick, G. (2010) Building A Future for Wildlife'? Evaluating the Contribution of the World Zoo and Aquarium Community to in-situ Conservation. *International Zoo Yearbook*, **44**, pp. 183-191.

Habibi, K. (2011) Dorcas gazelle (*Gazella dorcas*) and Pelzeln's gazelle (*Gazella pelzelni*). In: Wilson, D. E. and Mittermeier, R. A. (eds.), *Handbook of the Mammals of the World, Vol. 2. Hoofed Mammals*. Barcelona: Lynx Edicions, p. 641.

Hadas, L., Hermon, D., Boldo, A., Arieli, G., Gafny, R., King, R. and Bar-Gal, K. G. (2015) Wild Gazelles of the Southern Levant: Genetic Profiling Defines New Conservation. Priorities, *Plos One* [online] **10**(3) [Accessed 11 April 2017] Available at: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0116401.

Haltennorth, T. and Diller, H. (1997) *Mammals of Africa including Madagascar*, London: Harper Collins.

Hammarberg, K., Kirkman, M. and de Lacey, S. (2016) Qualitative research methods: when to use them and how to judge them. *Human Reproduction*. **31**(3) pp. 498–501.

Hammond, L. R., Macasero, W., Flores, B., Mohammed, B. O., Wacher, T., and Bruford, W. M. (2001) Phylogenetic Reanalysis of the Saudi Gazelle and Its Implications for Conservation. *Conservation Biology*, **4(**15), pp. 1123-1133.

Hayek, T., Lloyd, N., Stanley-Price, M. R., Saxena, A. and Moehrenschlager, A. (2016) *An Exploration of Conservation Breeding and Translocation Tools to Improve the Conservation Status of Boreal Caribou Populations in Western Canada* Calgary: Centre for Conservation Research.

Hegazy, A. K., Boulos, L., Kabiel, H. F. and Sharashy, O. S. (2011) Vegetation and Species Altitudinal Distribution in Al-Jabal Al-Akhdar Landscape. *Pakistan Journal of Botany*, **43**(4), pp. 1885-1898.

Heyman, J. (2011) *Questionnaire Design: An Expert Approach*. [online] [Accessed 20 September 2018] Available at: http://www.infosurv.com/wp-content/uploads/2011/01/Questionnaire_Design.pdf.

Hill, K., Padwe, J., Bejyvagi, C., Bepurangi, A., Jakugi, F., Tykuarangi, R. and Tykuarangi, T. (1997) Impact of hunting on large vertebrates in the Mbaracayu reserve, Paraguay. *Conservation Biology*, **11**, 1339-1353.

Hogg, C. J. (2013) Preserving Australian native fauna: zoo-based breeding programs as part of a more unified strategic approach. *Australian Journal of Zoology*, **61**(1), pp. 101-108.

Höglund, J. (2009) *Evolutionary Conservation Genetics*. Oxford: Oxford University Press.

Huff, M. H., Bettinger, K. A., Ferguson, H. L., Brown, M. J. and Altman, B. (2000) A habitat-based point-count protocol for terrestrial birds, emphasizing Washington and Oregon. U.S. Department of Agriculture, Forest Service. Gen. Tech. Rep. PNW GTR-501. Northwest Research Station. 39 p. [Accessed 3 August 2018] Available online at: <https://www.fs.fed.us/pnw/pubs/gtr501.pdf>.

Hufnagl, E. (1972) *Libyan Mammals*. Cambridge: Oleander Press.

IBM (2017) *Statistical Package for the Social Sciences (SPSS)Version 24.* [online] [Accessed 3 February 2017] Available at: <https://www.ibm.com/products/spss-statistics>.

International Union for the Conservation of Nature and Species Survival Commission (IUCN/SSC) Antelope Specialist Group (2008) *Gazella dorcas.*

The IUCN Red List of Threatened Species. [Accessed 15 June 2017] Available at: http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T8969A12941858.en.

International Union for the Conservation of Nature (IUCN) (2012) *Gnusletter* **30**(1).

International Union for the Conservation of Nature and Species Survival Commission (IUCN/SSC) (2013) *Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0.* Gland: IUCN/SSC.

International Union for the Conservation of Nature (IUCN) (2017) *Red List of Threatened Species* [online] [Accessed 6 June 2017] Available at: <http://www.iucnredlist.org/>.

International Union for the Conservation of Nature (IUCN) (2018) *Conservation strategy and action plan for Cuvier's gazelle (Gazella cuvieri) in North Africa 2017-2026.* IUCN Gland, Switzerland and Malaga, Spain: pp, x + 42. <https://doi.org/10.2305/IUCN.CH.2018.02.en>.

Iraossi, G. (2006) *The Power of Survey Design: A User's Guide for Managing Surveys, Interpreting Results, and Influencing Respondents*. Washington, D.C. The World Bank.

Islam, Z. M., Wacher, T., Boug, A. and Wronski, T. (2012) Population development of re-introduced Mountain gazelle in the western Empty Quarter (Uruq Bani Ma'arid Protected Area), Saudi Arabia. In P. S. SOORAE (Ed), Global re-introduction perspectives: 2011. Additional case studies from around the globe - IUCN/SSC Re-introduction Specialist Group (RSG), Abu Dhabi, UAE. pp. 180-184.

Isohelix (2015) *Instructions for Isohelix Xtreme DNA Kit: XME-5/50.* [Accessed 5 March 2015]. Available at: http://www.isohelix.com/PDF/Xtreme_Kit_Instructions.pdf.

Jachmann, H. (1991) Evaluation of four survey methods for estimating elephant densities, African*. Journal of Ecology*, **29**(3), 188-195.

Jebali, A. (2016) *Discussion about conservation of Dorcas gazelle during the Sahara Conservation Fund Conference*. Barcelona, 2 April 2016.

Jones, B. (2012) 'Recognition and Support of ICCAs in Namibia' in Kothari, A. with Corrigan, C., Jonas, H., Neumann, A., and Shrumm, H. (eds). *Recognising and Supporting Territories and Areas Conserved by Indigenous Peoples and Local Communities: Global Overview and National Case Studies.* Secretariat of the Convention on Biological Diversity, ICCA Consortium, Kalpavriksh, and Natural Justice, Montreal, Canada. Technical Series no. 64.

Karris, G., Fric, J., Kitsou, Z., Kalfopoulou, J., Giokas, S., Sfenthourakis, S. and Poirazidis, K. (2013) Does by-catch pose a threat for the conservation of seabird populations in the southern Ionian Sea (eastern Mediterranean)? A questionnaire-based survey of local fisheries. *Mediterranean Marine Science*, **14**(3), pp. 19-25.

Khattabi, K. and Mallon, D. P. (2001) Libya. In Mallon, D.P. and Kingswood, S. C. (eds). *Antelopes. Part 4: North Africa, the Middle East, and Asia. Global Survey and Regional Action Plans*. Gland: IUCN, pp. 41-47.

Kingdon, J. (2016) *The Kingdon Pocket Guide to African Mammals, 2nd ed, first published*. Bloomsbury Natural History.

Kingswood, S. C., Mallon, D. P. and Grubb, P. (2001) Classification of Antelopes Adopted for the Antelope Survey. In Mallon, D. P. and Kingswood, S. C.(eds). *Antelopes. Part 4: North Africa, the Middle East, and Asia. Global Survey and Regional Action Plans*. Gland: IUCN, pp. 7-9.

Knight, M. H., Novellie, P., Holness, S., Toit, J., Ferreira, S., Hofmeyr, M., Grant, C., Herbst, M. and Gaylard, A. (2016) Hands-on Approaches to Managing Antelopes and their Ecosystems: A South African Perspective. In Bro-Jorgensen, J. and Mallon, D. P. (eds) (2016) *Antelope Conservation: From Diagnosis to Action*. Chichester: John Wiley and Sons.

Krebs, C. J., Boonstra, R., Nams, V., O'Donoghue, M., Hodges, K. E. and Boutin, S. (2001) Estimating snowshoe hare population density from pellet plots: a further evaluation. *Canadian Journal of Zoology*, **79**(1), pp. 1-4.

Kritzer, J. P. and Sale, P. F. (eds) (2006) *Marine metapopulations*, Academic Press, New York.

Lafontaine, R. M., Beudels-Jamar, R. C., Devillers, P. and Wacher, T. (2005) Dorcas gazella. In: R. C. Beudels, P. Devillers, R. M. Lafontaine, J. Devillers-Terschuren and M. O. Beudels (eds), Sahelo-Saharan Antelopes. Status and Perspectives. Report on the conservation status of the six Sahelo-Saharan Antelopes. CMS SSA Concerted Action. 2nd edition. CMS Technical Series Publication N°11, 2005. UNEP/CMS Secretariat, Bonn, Germany.

Laing, S. E., Buckland, S. T., Burns, R. W., Lambie, D. and Amphlett, A. (2003) Dung and nest surveys: estimating decay rates. *Journal of Applied Ecology*, **40**(6), pp.1102-1111.

Lamprey, H. F. (1964) Estimation of large mammal densities, biomass and energy exchange in the Tarangire Game Reserve and Massai steppe in Tanganyika. *African Journal of Ecology,* **2**(1), pp.1-46.

Laurance, W. F. (2013) Does research help to safeguard protected areas? *Trends in Ecology and Evolution*, **28**(5), pp. 261-266.

Lee, T. M. and Jetz, W. (2008) Future battlegrounds for conservation under global change. *Proceedings of the Royal Society B,* **275**(1640), pp. 1261-1270.

Leigh, J. W. and Bryant, D. (2015) Application POPART: full-feature software for haplotype network construction. *Methods in Ecology and Evolution*, (9), pp. 1110-1116.

Lerp, H., Wronski, T., Pfenninger, M. and Plath, M. (2011) A phylogeographic framework for the conservation of Saharan and Arabian Dorcas gazelles (Artiodactyla: Bovidae). *Organisms Diversity and Evolution*, **11**(4), pp. 317-329.

Lerp, H., Wronski, T., Plath, M., Schröter, A. and Pfenninger, M. (2013) Phylogenetic and population genetic analyses suggest a potential species boundary between Mountain (*Gazella gazella*) and Arabian Gazelles (*Gazella arabica*) in the Levant. *Mammalian Biology - Zeitschrift Für Säugetierkunde*, **78**(5), pp. 383-386.

Leus, K., Traylor-Holzer, K. and Lacy, R. C. (2011) Genetic and Demographic population management in zoos and aquariums: recent developments, future challenges and opportunities for scientific research. *International Zoo Yearbook*, **45**, 213-225.

Levins, R. (1969), "Some demographic and genetic consequences of environmental heterogeneity for biological control". *Bulletin of the Entomological Society of America*, **15**, 237-240.

Lincoln, Y. S. and Guba, E. G. (2000) Paradigmatic controversies, contradictions, and emerging confluences. In N. K. Denzin, and Y. S. Lincoln. (Eds.), *Handbook of qualitative research* (2nd ed.), pp. 163-188. Thousand Oaks, CA: Sage.

Loggers, C. (1992) Population Characteristics of Dorcas gazelles in Morocco. *African Journal of Ecology*, **30**(4), pp. 301-308.

Macdonald, D. and Sillero-Zubiri, C. (2004) *Biology and conservation of wild canids*, Oxford University press, Oxford.

Magurran, A. E. and Dornelas, M. (2010) Biological diversity in a changing world Introduction. *Philosophical Transactions of the Royal Society B-Biological Sciences*, **365**, 3593-3597.

Mallinson, J. J. C. (2003) A Sustainable Future for Zoos and Their Role in Wildlife Conservation. *Human Dimensions of Wildlife*, **8**(1), pp. 59-63.

Mallon, D. P. and Kingswood, S. C. (2001) *Antelopes. Part 4: North Africa, the Middle East, and Asia*. Global Survey and Regional Action Plans. IUCN, Gland, Switzerland and Cambridge, UK.

Marques, F. F. C., Buckland, S. T., Goffin, D., Dixon, C. E., Borchers, D. L., Mayle, B. A. and Peace, A. J. (2001) Estimating deer abundance from line transect surveys of dung: sika deer in southern Scotland. *Journal of Applied Ecology*, **38**(2), pp. 349-363.

Marques, F. F. C. and Buckland, S. T. (2003) Incorporating covariates into standard line transect analyses. *Biometrics*, **59**(4), pp. 924-935.

Marques, T. A., Thomas, L., Fancy, S. G. and Buckland, S. T. (2007) Improving estimates of bird density using multiple covariate distance sampling. *The Auk*, **12**4(4), pp, 1229-1243.

Marques, T. A. (2009) Distance Samoling: Estimating Animal Density. *Significance,* **6**(3) pp. 136-137.

Matthews, J. (2006) The language and culture of research. *Practice Nurse*, **32**(2), pp.47-50.

Maunder, M. and Byers, O. (2005) The IUCN Technical Guidelines on the Management of Ex Situ Populations for Conservation: reflecting major changes in the application of ex situ conservation. *Oryx*, **39**(1), pp. 95-98.

Mayle, B. A., Peace, A. J. and Gill, R. M. A. (1999) *How Many Deer? A Field Guide to Estimating Deer Population Size.* Edinburgh: Forestry Commission.

Mendelssohn, H. and Yom-Tov, Y. (1987) *Plants and animals of the land of Israel: an illustrated encyclopedia: Vol 7: Mammals*. Tel Aviv**:** Ministry of Defence (in Hebrew).

Miller, R. and Waits, L. P. (2003) The history of effective population size and genetic diversity in the Yellowstone grizzly (Ursus arctos): Implications for conservation. *Proceedings of the National Academy of Sciences of the United States of America*, **100**(7), pp. 4334-4339.

Misonne, X. and Capocaccia, L. (1977) Mammifères du Jebel Uweinat, desert de Libya. Annales du Musée Royal de l'Afrique Central, *Tervuren*, **217,** pp. 1-33.

Mitchell, B., Rowe, J. J., Ratcliffe, P. R. R. and Hinge, M. (1985) Defaecation frequency in roe deer (*Capreolus capreolus*) in relation to the accumulation rates of faecal deposits. *Journal of Zoology* **207**(1), pp. 1-7.

Mooty, J. J. and Karns, P. D. (1984) The relationship between white-tailed deer track counts and Pellet-group surveys. *Journal of Wildlife Management*, **48**(1), pp. 275-279.

Morgan, D. L. (2008) *The SAGE Encyclopedia of Qualitative Research Methods.* London: Sage.

National Centre for Biotechnology Information (NCBI) (2016) *Nucleotide: Dorcas gazelle*. [online] [Accessed 2 February 2016] Available at: https://www.ncbi.nlm.nih.gov/nuccore/?term=dorcas+gazelle.

Newby, J., Wacher, T., Durant, S. M., Pettorelli, N. and Gilbert, T. (2016) Desert antelopes on the brink: How resilient is the Sahelo-Saharan ecosystem? In Bro-Jørgensen, J. and. Mallon, D. P (eds.), *Antelope Conservation: From Diagnosis to Action* Chichester, John Wiley and Sons, pp. 253-279.

Newey, S., Bell, M., Enthoven, S. and Thirgood, S. (2003) Can distance sampling and dung plots be used to assess the density of mountain hares Lepus timidus? *Wildlife Biology*, **3**, 185-192.

Newing, H., Eagle, C. M., Puri, R. K and Watson, C. W. (2011) *Conducting research in conservation: social science methods and practice*, Routledge, New York, USA.

Newson, S. E., Evans, K. L., Noble, D. G., Greenwood, J. D. and Gaston, K. J. (2008) Use of distance sampling to improve estimates of national population sizes for common and widespread breeding birds in the UK. *Journal of Applied Ecology*, **45**, 1330-1338.

Nowell, L. S., Norris, J. M., White, D. E. and Moules, N. J. (2017) Thematic analysis: Striving to meet the Trustworthiness criteria. *International Journal of Qualitative Methods,* **16** pp. 1-13.

Noyes, J. H., Johnson, B. K., Riggs, R. A. and Coggins V. L. (2000) Assessing aerial survey methods to estimate elk populations: a case study. *Wildlife Society Bulletin*, **28**(3), pp. 636-642.

Olds, L. G. M (2014) *Preliminary feasibility study of establishing a captive bred Mallee Emu-wren Stipiturus mallee ex situ insurance population*. *Report for Department of Environment, Water and Natural Resources, South Australia.* Melbourne: Birdlife Australia.

Ostrowski, S. and Williams, J. B. (2006) Heterothermy of free-living Arabian sand gazelles (*Gazella subgutturosamarica*) in a desert environment. *Journal of Experimental Biology,* **209**(8), pp.1421-1429.

Owen, A., Wilkinson, R. and Sözer, R. (2014) *In situ* conservation breeding and the role of zoological institutions and private breeders in the recovery of highly endangered Indonesian passerine birds. *International Zoo Yearbook*, **48**(1), pp. 199-211.

Palumbi, S. R. (1996) *Nucleic acids II: the polymerase chain reaction*. In: Hillis, DM., Moritz, C., and Mable, BK (eds). *Molecular systematics*. Sinauer Associates Inc, Sunderland, pp 205-247.

Perrine, J. D., Pollinger, J. P., Sacks, B. N., Barrett, R. H. and Wayne, R. K. (2007) Genetic evidence for the persistence of the critically endangered Sierra Nevada red fox in California. *Conserv Genet*, **8**, 1083-1095.

Price, S. A. and Gittleman, J. L. (2007) Hunting to extinction: biology and regional economy influence extinction risk and the impact of hunting in artiodactyls. *Proceedings of the Royal Society B* **274**(1620), pp. 1845-1851.

Pritchard, D. J., Fa, J. E, Oldfield, S. and Harrop, S. R. (2012) Bring the captive closer to the wild: redefining the role of ex situ conservation. *Oryx*, **46**(1), pp. 18-23.

Pullin, A. S. (2002) *Conservation Biology*. Cambridge: Cambridge University Press.

Putman, R. J. (1984) Facts from faeces. *Mammal Review*, **14**(2), pp. 79-97.

Putman, R., Watson, P. and Langbein, J. (2011) Assessing deer densities and impacts at the appropriate level for management: a review of methodologies for use beyond the site scale. *Mammal Review*, 197–219.

Qiagen (2006) *DNeasy® Blood and Tissue Handbook*. [Accessed 3 March 2015]. Available at: <https://www.qiagen.com/us/resources/resourcedetail?id=6b09dfb8-6319-464d-996c-79e8c7045a50&lang=en>.

Rands, M. R. W., Adams, W. M., Bennun, L., Butchart, S. H. M., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J. P. W., Sutherland, W. J. and Vira, B. (2010) Biodiversity Conservation: Challenges Beyond 2010. *Science*, **329**(5997), pp.1298-1303.

Reed, M. (2008) Stakeholder participation for environmental management: a literature review. *Biological Conservation*, **141**(10), pp. 2417-2431.

Reed, D. H., O'Grady, J. J., Brook, B. W., Ballou, J. D. and Frankham, R. (2003) Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. *Biological Conservation*, **113**(1), pp. 23-34.

Rebholz, W. E. R., Williamson, D. and Rietkerk, F. (1991) Saudi Gazelle (*Gazella saudiya*) is not a subspecies of Dorcas Gazelle. *Zoo Biology*, **10**(6), pp. 485-489.

Rebholz, W. and Harley, E. (1999) Phylogenetic relationships in the bovid subfamily Antilopinae based on mitochondrial DNA sequences. *Molecular Phylogenet and Evolution*, **12**, 87-94.

Redford, K. H., Amato, G., Baillie, J., Beldomenico, P., Bennett, E. L., Clum, N., Cook, R., Fonseca, G., Hedges, S., Launay, F., Lieberman, S., Mace, G. M., Murayama, A., Putnam, A., Robinson, J. G., Rosenbaum, H., Sanderson, E. W., Stuart, S. N., Thomas, P. and Thorbjarnarson, J. (2011) What Does It Mean to Successfully Conserve a (Vertebrate) Species? *Bioscience*, **61**(1), pp. 39-48.

Republic of Tunisia (2010) *Code Forestier et ses textes d'application*. [Accessed 11 November 2018] Available at: < http://www.droit-afrique.com/upload/doc/tunisie/Tunisie-Code-2010-forestier.pdf>.

Rigg, R. and Sillero-Zubiri, C. (2010) *Mitigating human- wildlife conflict in East Georgia. Phase 1: baseline survey of human-carnivore conflicts. Final report*. Georgian carnivore conservation project.

Robert, A. (2006) Negative environmental perturbations may improve species persistence. *Proceedings of the Royal Society B*, **273**(1600), pp. 501-2506.

Rostron, J. (1972) A multivariate statistical study of skull measurements of five taxa of gazelles. *Biological Journal of the Linnean Society*, **4**(1), pp. 1-14.

Royal Zoological Society of Scotland (RZSS) and IUCN Antelope Specialist Group (2014) Dama gazelle (*Nanger dama*), Conservation Review. Royal Zoological Society of Scotland, Edinburgh, UK.

Ryder, O. A. (1987) Conservation Action for Gazelles: Urgent Need. *Trends in Ecology and Evolution*, **2**(6), pp. 143-144.

Saad, A. M. A., Shariff, N. M. and Gairola, S. (2011) “Nature and Causes of land Degradation and Desertification in Libya: Need for Sustainable Land Management”. *African Journal of Biotechnology*, **10**(63), pp. 13680-13687.

Saatoğlu, D. (2015) *Genetic diversity of gazelles (Gazella marica* and *Gazella gazella) in southeast Turkey: with a special emphasis on on-going conservation studies of Gazella marica in Turkey*. Masters’ Dissertation: Middle East

Technical University [online] [Accessed 4 May 2017] Available at: http://etd.lib.metu.edu.tr/upload/12619540/index.pdf.

Sahara Conservation Fund (SCF). (2012) Massive wildlife slaughter. *Sandscript*, **12,** pp. 4.

Sahara Conservation Fund (SCF). (2015) Disaster in the desert. *Sandscript*, pp.1.

Salas, M., Manteca, X., Abáigar, T., Delclaux, M., Enseñat, C., Martínez-Nevado, E., Quevedo, M. A. and Fernández-Bellon, H. (2018) Using Farm Animal Welfare Protocols as a Base to Assess the Welfare of Wild Animals in Captivity-Case Study: Dorcas gazelle (*Gazella dorcas*). *Animals*, **8**(111), doi:10.3390/ani8070111.

Saleh, M. A. (1987) The Decline of gazelles in Egypt. *Biological Conservation*, **39**(2), pp. 283-295.

Sambrook, J., Fritsch, E. F. and Maniatis, T (1989) *Molecular Cloning: A Laboratory Manual*, *2nd ed.* New York. Cold Spring Harbor Laboratory Press.

Sandbrook, C., Adams, W. M., Büscher, B. and Vira, B. (2013) Social research and biodiversity conservation. *Conservation Biology*, **27**, pp. 1487-1490.

Saunders, M., Lewis, P. and Thornhill, A. (2009) *Research Methods for Business Students*. *5th edition*. Harlow: Prentice Hall.

Scholte, P. and Hashim, M. (2013) *Eudorcas rufifrons Red-fronted Gazelle dorcas*. In Kingdon, J., and Hoffmann, M. (Eds). *Mammals of Africa Vol 6* London: Bloomsbury Publishing, pp. 357-359.

Schultz, P. W., Gouveia, V. V., Cameron, L. D., Tankha, G., Schmuck, P. and Franěk, M. (2005) Values and their relationship to environmental concern and conservation behavior. *Journal of Cross-Cultural Psychology*, **36**(4), pp. 457-475.

Seber, G. A. F. (1982) *The Estimation of Animal Abundance and Related Parameters*, *2nd ed.* New York: MacMillan.

Senn, H., Banfield, L., Wacher, T., Newby, J., Rabeil, T., Kaden, J., Kitchener. C. A., Abaigar. T., Silva. L.T., Maunder. M. and Ogden, R. (2014) Splitting or Lumping? A Conservation Dilemma Exemplified by the Critically Endangered Dama Gazelle (*Nanger dama*). *Plos One* [online], **9**(6), [Accessed 28 June 2016] Available at: <http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0098693&type=printable>.

Shaffer, M. L. (1981) Minimum population sizes for species conservation. *BioScience*, **31**(2), pp. 131-134.

Sheskin, I. (1985) Survey Research for Geographers. *Resource Publications in Geography*, American Association of Geographers, Washington, D.C.

Siegle, D. (2018) *Educational Research Basics* [online] [Accessed 3 November 2018] Available at: < https://researchbasics.education.uconn.edu/>.

Sillero-Zubiri, C., Sukumar, R. and Treves, A. (2007) Living with wildlife, the roots of conflict and the solutions: In MacDonald, D., and Service, K. *Key Topics in Conservation Biology*. Oxford: Blackwell Publishing, pp. 266-272.

Sillero-Zubiri, C., Burruss, D., Matchano., A. and Robinson, O. (2013) *Carnivores and Pastoralism in Termit and Tin-Toumma* [online] [Accessed 21 February 2017] Available at: https://www.wildcru.org/wp-content/uploads/2014/07/Carnivores-and-Pastoralism-in-Niger-Termit-Tin-Toumma-Reserve-Nov-2013.pdf.

Simpson, D. J. and Hunt, C. O. (2009) Scoping the past human environment, a case study of pollen taphonomy at the Haua Fteah, Cyrenaica, Libya. *Archaeological Review from Cambridge*, **24**(2), 27-46.

Sinclair, A. R. (2015) Protected areas are necessary for conservation. In Protecting the Wild: Parks and Wilderness, the Foundation for Conservation: 72-79. Wuerthner, G., Crist, E. and Butler, T. (Eds.). Washington DC: Island Press.

Smart, J. C. R., Ward, A. I. and White, P. C. L. (2004) Monitoring woodland deer populations in the UK: an imprecise science. *Mammal Review,* **34**(1-2), pp. 99-114.

Smith, S. L., Stober, J., Balbach, E. H and Meyer, D. W. (2009) *Gopher Tortoise Survey Handbook.* Wasington D. C.: Engineer Research and Development Center.

SSIG. (2002) *Report of the Third Annual Sahelo-Saharan Interest Group Meeting* [online] [Accessed 4 June 2017] Available at:
http://abdoulkarimsow.org/scf2016/IMG/pdf/SSIG_2002_Bratislava_Slovakia.pdf.

SSIG. (2003) *Report of the Fourth Annual Sahelo-Saharan Interest Group Meeting*. online] [Accessed 7 June 2015] Available at:
http://abdoulkarimsow.org/scf2016/IMG/pdf/SSIG_2003_Agadir_Morocco-2.pdf.

Sournia, G. and Dupuy, A. R. (1990) Chapter 7: Senegal. In: East R (ed) Antelopes. Global survey and regional action plans. Part 3. West and Central Africa. Gland, IUCN. pp29-32.

Stabach, A. J., Rabeil, T., Turmine, V., Wacher, T., Mueller, T. and Leimgruber, P. (2017) On the brink of extinction - Habitat selection of Addax and Dorcas gazelle across the Tin Toumma desert, Niger. *Diversity and Distributions,* **23**(6), pp. 581-591.

Stanley-Price, M. R. (2016) Reintrduction as an Antelope Conservationm Solution. in Bro-Jorgensen, J. and Mallon, D. P. (eds) *Antelope Conservation: From Diagnosis to Action*. Chichester: John Wiley and Sons. pp. 217-252.

Stork, N. E. (2010) Re-assessing current extinction rates. *Biodiversity and Conservation*, **19**(2), pp. 357-371.

Strindberg, S., Buckland, S. T. and Thomas, L. (2004) Design of distance sampling surveys and Geographic Information Systems. In. Buckland, S. T, Anderson, D. R., Burnham, K. P., Laake, J. L, Borchers, D. L. and. Thomas, eds), *Advanced Distance Sampling* Oxford: Oxford University Press, pp. 190-228.

Suárez, A., Williams-Linera, G., Trejo, C., Valdez-Hernández, JI., Cetina-Alcalá, V. M. and Vibrans, H. (2012) Local knowledge helps select species for forest restoration in a tropical dry forest of central Veracruz, Mexico. *Agroforestry Systems*, **85**, pp. 35-55.

Sunderland, E. and Rosa, P. (1976) “The Incidence of Red-Green Color Blindness in the Populations of Tripolitania, Cyrenaica and Fezzan in Libya, and of the Kikuyu, Kamba, Taita, Taveta and Luo Tribes of Kenya”. *American Journal of Physical Anthropology*, **44**, 151-156.

Sutherland, W. J. (1996) *Ecological Census Techniques: A handbook*, Cambridge: Cambridge University Press.

Sutherland, W. J. (2006) *Ecological Census Techniques: A handbook, 2nd ed,* Cambridge: Cambridge University Press.

Swanson, G., Campbell, D. and Armstrong, H. (2008) *Estimating deer abundance in woodlands: the combination plot technique*. [online] [Accessed 7 April 2017] Available at: https://www.forestry.gov.uk/pdf/FCBU128.pdf/$FILE/FCBU128.pdf.

Tamura, K., Stecher, G., Peterson, D., Filipski, A. and Kumar, S. (2013) MEGA6: molecular evolutionary genetics analysis version 6.0. *Molecular biology and evolution*, **30**(12), pp. 2725-2729.

Tashakkori, A. and Creswell, J. (2007) The new era of mixed methods. *Journal of Mixed Methods Research*, **1**(1), 3-7.

Tchernov, E., Dayan, T. and Yom-Tov, Y. (1986) The paleogeography of *Gazella gazella* and *Gazella dorcas* during the holocene of the southern Levant. *Israel Journal of Zoology*, **34**(1-2), pp. 51-59.

Tear, T. H., Mosley, J. C. and Ables, E. D. (1997) Landscape-scale foraging decisions by reintroduced Arabian oryx. J. *Journal of wildlife management,* **61**(4), pp. 1142-1154.

Thomas, L., Buckland, S. T., Rexstad, E. R., Laake, J. L., Strindberg, S. and Hedley, S. L. (2010) Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, **47**(1), pp. 5-14.

Thompson, B. (1999) Journal editorial polices regarding statistical significance tests: Heat is to fire as p is to importance. *Educational Psychology Review*, **11**(2), 157-169.

UNEP/CMS. (1999) *Conservation measures for Sahelo-Saharan Antelopes. Status Report. CMS Technical Series Publication No 4*. Bonn: UNEP/CMS.

UNEP/WCMC (2007) *Review Reports: Concerted Action Species. Part 1 Terrestrial Mammals* [online] [Accessed 2 January 2016] Available at: http://www.cms.int/aquaticmammals/sites/default/files/document/ScC13_Doc_07_Attach1_Review_CASp_TerMam_E_0.pdf.

Urbaniak, G. C. and Plous, S. (2014) *Research Randomizer* [online] [Accessed June 2015] Available at: https://www.randomizer.org.

Valente, A. M, Fonseca, C., Marques, T. A., Santos, J. P., Rodrigues, R. and Torres, R. T. (2014) Living on the Edge: Roe Deer (*Capreolus capreolus*) Density in the Margins of Its Geographical Range. *PLoS ONE*, **9**(2), e88459. doi:10.1371/journal. pone. 0088459.

Vaske, J. J., Bearman, J. and Sponarski, C. C. (2017) Rethinking Internal Consistency in Cronbach's Alpha. *Leisure Sciences*, **39**(2) pp. 163 – 173.

Veiga, M. M. (2016) *Update on demographic and genetic parameters of a captive population of threatened Saharawi dorcas gazelle (Gazella dorcas neglecta).* Master's dissertation, University of Lisbon, Portugal.

Venter, F. J., Naiman, R. J., Biggs, H. C. and Pienaar, D. J. (2008) The evolution of conservation management philosophy: Science, environmental change and social adjustments in kruger national park. *Ecosystems*, **11**(2), pp. 173-192.

Verma, S. K. and Singh, L. (2003) Novel universal primers establish identity of an enormous number of animal species for forensic application. *Molecualr Ecology Resources*, **3**(1), pp. 28-31.

Wacher, T. and Newby, J. (2010) *Wildlife and land use survey of the Manga and Eguey regions* [online] [Accessed 4 September 2017] Available at: https://www.saharaconservation.org/sites/default/files/201702/PSWS_Technical_Report_04_Manga-Eguey_Chad_2010_English.pdf.

Wacher, T., Wronski, T., Hammond R. L., Winney, B., Blacket, M. J., Hundertmark, K. J., Mohammed, O. B., Omer, S. A., Macasero, W., Lerp, H., Plath, M. and Bleidorn, C. (2011) Phylogenetic analysis of mitochondrial DNA sequences reveals polyphyly in the goitred gazelle (*Gazella subgutturosa*). *Conservation Genetics*, **12**(3), pp. 827-831.

Wacher, T. and Newby, J. (2012) *Summary of Results and Achievements of the Pilot Phase of the Pan Sahara Wildlife Survey 2009-2012*. [online] [Accessed 3 September 2017] Available at: https://www.zsl.org/sites/default/files/media/201404/PSWS_Technical_Report_13_Summary_Report_2012.pdf.

Wanyama, F., Muhabwe, R., Plumptre, J. A., Chapman, A. C. and Rothman, M. J. (2010) Censusing large mammals in Kibale National Park: evaluation of the intensity of sampling required to determine change. *African Journal of Ecology*, **48**, 953–961.

Ward, A. I., White, P. C. L. and Critchley, C. H. (2004) Roe deer *Capreolus capreolus* behaviour affects density estimates from distance sampling surveys. *Mammal Review,* **34**(4), 315-319.

Webster, M. (1985) *Webster`s nith new collegiate dictionary*. Meriam - Webster Inc.

White, P. C. L., Jennings, N. V., Renwick, A. R. and Barker, N. H. L. (2005) Questionnaires in ecology: a review of past use and recommendations for best practice. *Journal of Applied Ecology*, **42**(3), 421-430.

Williams, R. and Thomas, L. (2010) Cost-effective abundance estimation of rare marine animals: small-boat surveys for killer whales in British Columbia, Canada. *Biological Conservation*, **142**(7), pp. 1542-1547.

Wilson, R. J., Thomas, C. D., Fox, R., Roy, D. B. and Kunin, W. E. (2004) Spatial patterns in species distributions reveal biodiversity change. *Nature*, **432**(7015), pp. 393-396.

Wilson, E. O. and Reeder, D. M. (2005) *Mammal Species of the World: A Taxonomic and Geographic Reference 3rd ed*. Baltimore: Johns Hopkins University Press.

Wilson, D. E. and Mittermeier, R. A. (2011) *Handbook of the Mammals of the World. Vol 2.* Barcelona. Lynx Edicions.

Witmer, W. Gary. (2005) Wildlife population monitoring: some practical considerations. *USDA National Wildlife Research Center*. <http://digitalcommons.unl.edu/icwdm_usdanwrc/70>.

Woodroffe, R., Thirgood, S. J. and Rabinowitz, A. (2005) *People and wildlife: conflict or coexistence?* Cambridge University press, New York.

World Association of Zoos and Aquariums (WAZA) (2006) *Understanding Animals and Protecting Them - About the World Zoo and Aquarium Conservation Strategy*. [online] Accessed 5 October 2017. Available at: http://www.waza.org/files/webcontent/1.public_site/5.conservation/conservation_strategies/understanding_animals_brochure/Marketing%20brochure.pdf.

World Wide Fund for Nature (WWF) (2014) *Communal Conservancies: Namibia's Gift to the Earth.* Accessed 5 October 2018. Available at: < http://www.namibiatourism.com.na/uploads/file_uploads/Namibian_Conservation_Fact_Sheet_copy.pdf>.

Wronski, T. and Plath, M. (2010) Characterization of the spatial distribution of latrines in reintroduced mountain gazelles: do latrines demarcate female group home ranges? *Journal of Zoology*, **280**(1), 92-101.

Wronski, T., Wacher, T., Hammond, R. L., Winney, B., Hundertmark, K. J. and Blacket, M. J. (2010) Two reciprocally monophyletic mtDNA lineages elucidate the taxonomic status of Mountain gazelles (*Gazella gazella*). *Systematics and Biodiversity*, **8**(1) pp. 119-129.

Wronski, T., Zafar-ul Islam, M. and Plath, M. (2013) Litrine survey as a method to estimate the population size of Arabian gazelle (*Gazella arbica*): *Mammalian Biology*, **78**(3), pp. 226-230.

Yom-Tov. Y. and Ilani G. (1987) The numerical status of *Gazella dorcas* and *Gazella gazelle* in the southern Nagev Desert, *Israel. Biological Conservation*, **40**(4), pp. 245-253.

Yom-Tov Y., Mendelssohn H. and Groves C. P. (1995) *Gazella dorcas*. *Mammalian Species*, **491**, pp. 1-6.

Zedany, A. and Al-Kich, A. (2013) Libyan gazelle risk being ‘poached to extinction’. *France 24*, 01 February. Retrieved from https://observers.france24.com/en/20130201-libyan-militias-hobby- hunting-gazelles-poaching.

APPENDICES

Appendix 1: List of experts to whom the questionnaire was distributed.

(Respondents shown in the grey shaded areas)

Organisation	Representative/ Person	Position	Country	Contact
Libyan Wildlife Trust	Ahmed Elkesh	Founder of Libyan Wildlife Trust	Libya	a.a.elkesh@stir.ac.uk
Afdeling Natuur Sahara Conservation Fund	Koen De Smet	Secretary of the Board	Belgium	Koen.desmet@lin.vlaanderen.be
National Museums Scotland. (NMS)	Andrew Kitchener	Principal Curator of Vertebrates Department of Natural Sciences	United Kingdom	A.Kitchener@nms.ac.uk
EEZA/CSIC	Teresa Abaigar	Research Scientist, Estación Experimental de Zonas Aridas (CSIC)	Spain	abaigar@eeza.csic.es
IRSNB/CMS Conservation Biology Section. Institut Royal des Sciences Naturelles de Belgique	Roseline Beudels-Jamar De Bolsee	IRSNB, Conservation biology unit; chair of CMS ScC Terrestrial Mammals Working Group	Belgium	roseline.beudels@naturalsciences.be
Smithsonian Conservation Biology Institute	Pierre Comizzoli	Research Biologist	USA	comizzolip@si.edu
Agence Nationale pour la Conservation de la Nature, Algeria	Amina Fellous	Conservation - biologist	Algeria (DZ)	Fellousa2000@yahoo.fr
Saint Louis Zoo	Martha Fischer	Curator of Mammals, Ungulates; Director, WildCare Institute Center for Conservation in the Horn of Africa; Chair, AZA Antelope and Giraffe Taxon Advisory Group (TAG)	USA	fischer@stlzoo.org
Smithsonian Conservation Biology Institute. Conservation and Research Center. Smithsonian Institution	Steve Monfort	Director Research Veterinarian	USA	monforts@si.edu smonfort@cerc.si.edu
Sahara Conservation Fund	Thomas Rabeil	Regional Program Officer	France	thomas.rabeil@saharaconservation.org

Zoo Hannover	Heiner ENGEL		Germany	engel@zoo-hannover.de
EEZA. CSIC	Mar Cano		Spain	mar@eeza.csic.es
Museum National D; Histoire Naturelle. Department Ecologie et Geshon de la. Biodiversite	Françoise Claro	Menagerie du Jardin des Plantes	France	Claro@mnhn.fr
Foundation for the Conservation of Wildlife (IFCW)	Philippe Chardonnet		France	igf@fondation-igf.fr
Office National de la Classe et de le Faune. Sauvage	François Lamarque		France	f.lamarque@oncfs.gouv.fr
Marwell Preservation Trust. Colden Common (Marwell Wildlife)	Tania Gilbert	Conservation Biologist; Vice-chair, EAZA Antelope and Giraffe Taxon Advisory Group	United Kingdom (UK)	taniag@marwell.org.uk
Parcs Zoologique et Forestier--Hann Dakar-Fann	Demba Mamadou BA	Direction des Parcs Nationaux du Senegal	Senegal	dpn@sentoo.sn
Curator, Rotterdam Zoo	Angela Glatston		Netherlands	a.glatston@rotterdamzoo.nl
Saint Louis Zoo	Edward William (Bill) Houston	Assistant General Curator	USA	Houston@stlzoo.org
3 Rue Maarif	Hans Peter Muller		Morocco	hpmuller@mtds.com
Zoological Society of London (ZSL)	Tim Wacher	Senior Wildlife Biologist, Conservation Programes	United Kingdom (UK)	tim.wacher@zsl.org
Marwell Preservation Trust. Colden Common	Tim Woodfine	Head, Department of Conservation & Wildlife. Management	United Kingdom (UK)	timw@marwell.org.uk
Marwell Preservation Trust. Colden Common	Simon Wakefield		United Kingdom (UK)	swakefi594@a0l.com
Al Ain Zoo	Hessa Al Qahtani	Conservation Officer	UAE	Hessa.AlQahtani@alainzoo .ae
Al Ain Zoo	Lisa Banfield	Conservation Officer	UAE	lisa.banfield@alainzoo.ae
International Foundation for Wildlife Management	Philippe Chardonnet	Director; Co-Chair, IUCN SSC Antelope Specialist Group	France	p.chardonnet@fondation-igf.fr
Al Ain Zoo	Mark Craig	Director Life Sciences	UAE	mark.craig@alainzoo.ae
Fossil Rim Wildlife Center	Adam Eyres	Hoofstock Curator; Antelope and Giraffe Taxon Advisory Group-Aridland Antelope, Gazelle	USA	adame@fossilrim.org
Tunisia Wildlife Conservation Society	Abdelkader Jebali	Vice-President	Tunisia (TU)	jebali2004@yahoo.fr

IUCN	David Mallon	Co-Chair, IUCN SSC Antelope Specialist Group	United Kingdom	d.mallon@zoo.co.uk, dmallon7@gmail.com
Second Ark Foundation (SAF)/Exotic Wildlife Association (EWA)	Elizabeth Cary Mungall	SAF Science Officer/EWA Technical Advisor	USA	emungall@gmail.com
(TERC)	John Newby	Director, Terrestrial Environment Research Centre	United Arab Emirates	jnewby@erwda.gov.ae
Sahara Conservation Fund	John Newby	CEO	Chad (CH)	john.newby@bluewin.ch
WWF-International	John Newby		Switzerland	Jnewby@wwfint.org
RZSS	Rob Ogden	Director of Conservation	United Kingdom	rogden@rzss.org.uk
RZSS	Helen Senn	Research Scientist (conservation genetics)	United Kingdom	hsenn@rzss.org.uk
White Oak Conservation Holdings LLC	Brandon Speeg	Director of Conservation Education	USA	bspeeg@wogilman.com
Wildlife Conservation Research Unit, University of Oxford	Mark Stanley Price	Senior Research Fellow	United Kingdom (UK)	mark.stanleyprice@zoo.ox.ac.uk
RZSS	Caroline Whitson	Conservation Administrator	United Kingdom	cwhitson@rzss.org.uk
	Andras Zboray			andras@fjexpeditions.com
Zoo Frankfurt	Stefan G. Stadler	Kurator/Curator Vögel and Huftiere / Birds and Ungulates	Germany	stefan.stadler@stadt-frankfurt.de
Ministry of Forests, Land, Resource Operation, BC Canada and the Antelope Specialist Group at the IUCN	Husam El Alqamy	GIS Analyst	Canada	alqamy@gmail.com

Appendix 2: Experts questionnaire

University of Wolverhampton: Faculty of Science and Engineering

My name is Walid Algadafi and I am a PhD researcher at the University of Wolverhampton, UK, studying the Conservation Ecology of the Dorcas gazelle (*Gazella dorcas*) in North-East Libya. As part of my research I am undertaking a questionnaire based study exploring the current knowledge of the gazelle's populations, threats and conservation management. This questionnaire is concerned with your understanding, views and opinions regarding these areas and forms a significant part of the information that will be input to the final research outcomes. I would be very grateful if you could find the time to respond to these questions.

As you have been identified as someone who can give expert views on some or all of these aspects I would be grateful if you could add as much detail in your answers as possible. If you are unable to answer a question please indicate this by adding the phrase 'no details' in the questions answer space.

You are free to discontinue your involvement at any time and I can assure you that all the information provided will be treated in strict confidence and will be used for the purpose of this research alone.

Please return completed questionnaires to me at W.Agadafi@wlv.ac.uk. If you have any questions, please contact me at this email address. Finally, if you would like to receive a summary of the data associated with the questionnaire please notify me via the e-mail address on return of the questionnaire.

Thank you for your participation,

Yours faithfully,

Walid Algadafi

Lecturer in the Department of Environmental Sciences and Wildlife Conservation. Omar AL Mukhtar University, Libya

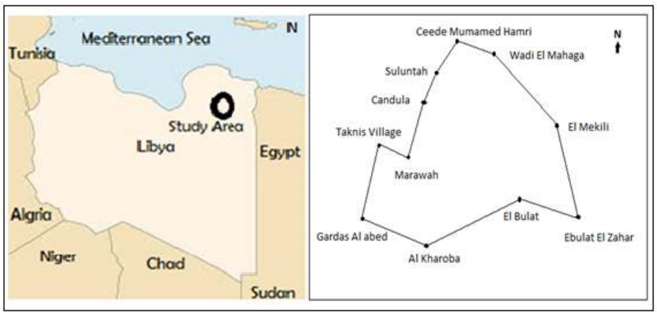


Fig. 1. General location of study area in Libya (left). Location of the study area (area south of the Green Mountain: approx. scale 300km X 300 km)

Questionnaire

Distribution and numbers of Dorcas gazelle

This section is looking to establish estimates of the population numbers and distribution of the Dorcas gazelle in Libya.

1. Where are they found in all areas of Libya (as much detail as possible)? How many Dorcas gazelles do you estimate there are in Libya? What sized groups do they tend to be found in?

----

2. Historically, how many Dorcas gazelles were there previously in Libya, when was this and what evidence do you have for this estimate?

----

3. Where are Dorcas gazelles in the study area as shown the map in Figure 1 (as much detail as possible)? How many Dorcas gazelles are there in the study area now? What sized groups do they tend to be found in?

----

4. Historically, how many Dorcas gazelles were there previously in the study area, when was this and what evidence do you have for this estimate?

Threats to Dorcas gazelle

This section explores the main issues that currently and historically affect Dorcas gazelle populations in Libya.

5. In your view what are the main threats to Dorcas gazelle across their natural range in Libya? Have these threats changed over the years? When was this?

----

6. In your view what are the main threats to Dorcas gazelle in the study area in north-east Libya (see fig. 1)? Have these threats changed? When was this?

Conservation and management of Dorcas gazelle in Libya

This section identifies the main measures that currently and historically affect the conservation and management of the Dorcas gazelle in Libya.

7. Based on your experience what are the current measures in your opinion that are being taken to conserve the Dorcas gazelle across its natural range in Libya? Have these measures changed? When was this?

----

8. Based on your experience what are the current measures in your opinion that are being taken to conserve the Dorcas gazelle in the study area (see fig 1) in north-east Libya? Have these measures changed? When was this?

----

9. What in your view are the main priority (priorities) and/or opportunities for conserving Dorcas gazelle in Libya? Do you think it is possible to restore numbers to historical levels? If so how?

----

10. Which are the key organizations involved in the conservation of the Dorcas gazelle worldwide and in Libya? Are there good examples from elsewhere in the world that could be used as models for the conservation and management of the Dorcas gazelle in Libya?

----

11. What do you think are the main obstacles to conservation of the Dorcas gazelle in Libya?

----

12. Are you aware of any other research in this topic? Are you aware of the existence of any data sets (current or historical) from Libya or elsewhere that would be useful?

----

13. Taking the information above, what in your opinion is the current status of the Dorcas gazelle in Libya? If so is there any other information you could add to this, e.g. reports, studies, personal experience?

----

14. Is there any other information that you think would be useful for this study, i.e. comments, observations or recommendations that would be helpful to maintaining the Dorcas gazelle?

----

15. Would you be willing to be contacted at some future occasion for a more focused interview on the issues raised in this questionnaire? Yes/No

----

Dorcas Gazelle populations, threats and conservation outside Libya

If you work with Dorcas Gazelle populations outside of Libya, either with captive or wild individuals/populations this section deals with the issues raised in the previous sections as they may apply to your geographical area of knowledge.

Distribution and numbers of Dorcas gazelle

16. Where are Dorcas Gazelles to be found in North Africa? How many Dorcas gazelles do you estimate there are in the wild in the region? What sized groups do they tend to be found in?

----

17. Historically, how many Dorcas gazelles were there previously across their range? When was this, and what evidence do you have for this estimate?

Threats to Dorcas gazelle

18. In your view what are the main threats to Dorcas gazelle across their natural range? Have these threats changed over the years? When was this?

Conservation and Management of Dorcas gazelle

19. Based on your experience what are the current measures in your opinion that are being taken to conserve the Dorcas gazelle across its natural range? Have these measures changed? When was this?

THANK-YOU very much for your time and participation

Appendix 3: Cover letter for expert questionnaire

Faculty of Science and Engineering
City Campus South
University of Wolverhampton
Wulfruna Street
Wolverhampton
WV1 1LY
01902 321000 (Switchboard)
01902 322680 (Fax)

Dear, ……….

My name is Walid Algadafi and I am a first year PhD student in the Faculty of Science and Engineering at the University of Wolverhampton, UK, studying the Conservation Ecology of the Dorcas gazelle (*Gazella dorcas*) in North East Libya. As part of my research I am undertaking a questionnaire-based study exploring the current knowledge of the gazelle's populations, threats and conservation management. My supervisory team consists of Dr Chris Young, Dr Lynn Besenyei and Dr Catherine Tobin, all senior lecturers at the university.

You have been identified as an expert in one of the areas of interest that my research is covering from your work with relevant organisations, your publications or else your contributions to/participation in relevant conferences or workshops. As such I would be grateful if you would be willing to participate in the research by responding to a questionnaire on the topic. If you could reply to this e-mail confirming your willingness to participate, I will then send you the questionnaire for completion.

As one of the outcomes from this phase of the research, I am aiming put together a brief summary of the main points and then send this out to all participants. Any formal outcomes, e.g. published papers or conference abstracts, I would also share directly with the questionnaire respondents. All information would be anonymised, and no sensitive information would be placed into the public domain.

I appreciate your time and effort and I hope you are able to participate in the study.

Kindest Regards,

Walid Algadafi

Appendix 4: In-country questionnaire 2015

UNIVERSITY OF WOLVERHAMPTON

جامعة عمر المختار
Omar Al-Mukhtar University

University of Wolverhampton: Faculty of Science and Engineering

Dear respondent,

My name is Walid Algadafi and I am a PhD researcher at the University of Wolverhampton, UK, studying the Conservation Ecology of the Dorcas gazelle (*Gazella dorcas*) in North East Libya (Fig. 1). As part of my research I am undertaking a questionnaire-based study exploring the current knowledge base of Dorcas gazelle populations, their threats and conservation management. This questionnaire is designed to study a sample of the Libyan community, to see the importance of this gazelle to the people of Libya, and also to find out the current distribution and numbers of Dorcas gazelle in Libya. I hope to understand the reasons that have led to the decline and endangered of this gazelle in Libyan territory. I would be very grateful if you could please cooperate with me, to gain scientific and accurate information, which can lead to safeguarding this gazelle in Libya (Fig. 2), which needs help and our protection.

This questionnaire is concerned with your understanding, views and opinions regarding this area of Libya and forms a significant part of the information leading to the final research outcomes. I would be very grateful if you could find the time to respond to these questions.

Thank you for completing this questionnaire about your feelings towards the wildlife, such as Dorcas gazelle, living in Libya. Your opinions about this animal are important and I greatly appreciate your time spent answering these questions thoughtfully. Whether your answers are positive, neutral or negative your views are very valuable to me, as we are trying to document the range of people's attitudes towards this species of gazelle. Your answers should represent your own opinions, not those of others. So, we encourage you to voice your opinions. Please answer all the questions, but do not take too long over this: it is not an exam!

Your individual responses will not be used for any purpose other than for this research and your response will be kept confidential. In completing the questionnaire, you are consenting for your data to be used in the study. Please feel free to express yourself as much as possible, and you are free to discontinue your involvement at any time.

Please return the completed questionnaire to me at W.Agadafi@wlv.ac.uk. If you have any questions, please contact me at this email address or call me on my mobile No: 0916393571.

Thank you for your participation,

Yours faithfully,

Walid Algadafi

Lecturer in the Department of Environmental Sciences and Wildlife Conservation. Omar AL Mukhtar University, Libya

PhD researcher at the University of Wolverhampton, UK

University of Wolverhampton: Faculty of Science and Engineering

Questionnaire

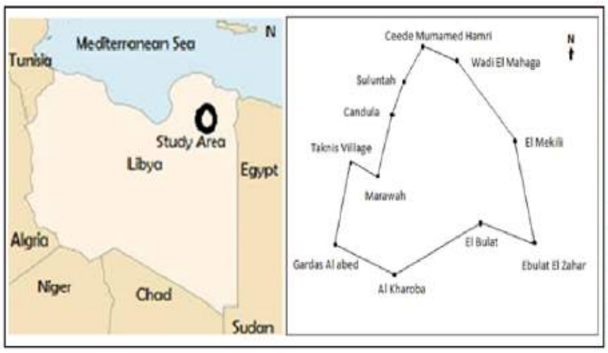


Fig. 1. General location of the study area in Libya and detail of the study area (South of the Green Mountain: approx. scale 300kmX300 km)

Fig. 2. The Dorcas gazelle

Gazelle are fast-moving graceful animals, with a beautiful shape. Dorcas gazelle are well-known in Libya and this has led to it becoming rare and endangered.

Knowledge, distribution, and numbers of Dorcas gazelle

This section looks to establish estimates of the population numbers and distribution of Dorcas gazelle in North East Libya.

1. In which kind of areas do the Dorcas gazelle live in Libya?

Please circle the response that best describes your opinion.

a.	Coastal areas	b.	Desert areas	c.	Mountainous areas	d.	Pre-Saharan region (semi-desert)
e.	Other:						

2. Have you ever seen the gazelle in the wild during the last 4 years? *Please indicate your knowledge of the Dorcas gazelle*. Yes ( ) No ( )

If yes, please give the places names, dates and numbers of Dorcas gazelle (where possible)?

----

3. What are the highest numbers of Dorcas gazelle that you have seen together during the last 4 years? *Please circle the response that best describes your opinion*.

a	One gazelle	b	Two gazelles	c	Three gazelles	d	4 - 5 gazelles	e	Small groups. How many? ………..	F	Large herds. How many?	g	None

4. Did you recognise the species of gazelle that you saw? Can you distinguish Dorcas gazelle from other gazelle species?

Please circle the response that best describes your opinion. Yes ( ) No ( )

If yes, please give the species:

I would like to ask you some questions on how the Dorcas gazelle numbers may have changed over the last 4 years in the area south of Green Mountain.

5. Do you think the numbers of Dorcas gazelle have changed or are staying the same? *Please circle the response that best describes your opinion*.

a.	Increasing	b.	Decreasing	c.	Staying the same	d.	I don't know

6. What is your estimate of the decrease or increase of Dorcas gazelle numbers during the last 4 years in areas where the gazelles have lived recently?

Please circle the response that best describes your opinion.

a.	Decrease	0 - 20 %	21 - 40 %	41 - 60 %	61 - 80 %	81 - 100 %
b.	Increase	0 - 20 %	21 - 40 %	41 - 60 %	61 - 80 %	81 - 100 %

Attitudes and threats to Dorcas gazelle and the reasons for these

This section explores the main issues that currently and historically affect Dorcas gazelle populations in Libya.

7. Do you think the conflict in Libya has led to increased pressures on wildlife and particularly on Dorcas gazelle? *Please provide an explanation*.

----

8. Please give your opinion on the importance of the following issues affecting Dorcas gazelle and all wildlife in the area south of Green Mountain?

Please circle the response that best describes your opinion.

	Positions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1.	There are too many gazelle	1	2	3	4	5
2.	The recent war in Libya (in 2011) has led to low numbers and the decrease of Dorcas gazelle					
3.	Overhunting has led to low numbers and the decrease of Dorcas gazelle	1	2	3	4	5
4.	A lot of gazelle are killed by hunters	1	2	3	4	5
5.	A lot of gazelle are killed by wild predators	1	2	3	4	5
6.	There are too many wild predators	1	2	3	4	5
7.	There are too many livestock	1	2	3	4	5
8.	Acquisition of hunting tools and modern means of transportation led to low numbers and the decrease of Dorcas gazelle	1	2	3	4	5
9.	Hunting at inappropriate times (e.g. mating season) has led to low numbers and the decrease of Dorcas gazelle	1	2	3	4	5
10.	A lack of environmental awareness of the value of Dorcas gazelle has led to low numbers and the decrease of this gazelle	1	2	3	4	5
11.	Communities and hunters need more information and awareness of the value of the gazelle	1	2	3	4	5
12.	Urbanization, including roads has led to low numbers and the decrease of Dorcas gazelle	1	2	3	4	5
13.	A lack of natural habitat, to provide food and water have led to low numbers and the decrease of Dorcas gazelle	1	2	3	4	5
14.	People in this area are hungry and therefore need to eat bush meat	1	2	3	4	5
15.	More research and monitoring are needed on the gazelle	1	2	3	4	5

9. If you know of any incidents when Dorcas gazelle or other gazelle species have been killed in Libya? If so, please describe (a) which gazelle species; (b) the date or year in which it occurred; (c) where it occurred (name of place); (d) the method used to catch and kill the gazelle; (e) the number killed; and (f) the reason why they were killed. Enter the information in the table below (one line for each incident):

	Positions	Incident (1)	Incident (2)	Incident (3)
a.	Species			
b.	Date trapped			
c.	Location			
d.	Method used			
e.	Number			
f.	Reason			

Occurrence of gazelle with other animal species and preferred vegetation species

10. Have you ever seen Dorcas gazelle associating with any other species of wild or domestic animal? *Please describe the association and give species names*.

----

11. Which plants have you seen the Dorcas gazelle eating? *Please give their names*.

Conservation and management and damage control measures for Dorcas gazelle

This section seeks to identify the main measures that currently and historically affect the conservation and management of the Dorcas gazelle in Libya.

12. In your opinion what would be the most effective Dorcas gazelle conservation measures that could be used at the present time in the Region South of Green Mountain?

Please circle the response that best describes your opinion.

	Positions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
a.	Protected areas (nature reserves)	1	2	3	4	5
b.	Captive breeding and reproduction of the gazelle	1	2	3	4	5
c.	Protection laws	1	2	3	4	5
d.	Education of all members of the community of the importance of wildlife	1	2	3	4	5
e.	Zoos	1	2	3	4	5

13. In your opinion what would be the most effective Dorcas gazelle conservation measures that could be used in the future in the Region South of Green Mountain?

Please circle the response that best describes your opinion.

	Positions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
a.	Protected areas (nature reserves)	1	2	3	4	5
b.	Captive breeding and reproduction of the gazelle	1	2	3	4	5
c.	Protection laws	1	2	3	4	5
d.	Education of all members of the community of the importance of wildlife	1	2	3	4	5
e.	Zoos	1	2	3	4	5

14. Do you believe that the above measures would provide effective protection of Dorcas gazelle populations in the region? Yes ( ) No ( )

If yes, which groups have a role in the implementation and enforcement of such measures?

Please give the answer that best describes your opinion.

a.	Government sector	b.	International organizations
c.	Local communities	d.	National organizations
e.	Other:		

15. What are the reasons that have led to low numbers and the extinction of the Dorcas gazelle in parts of Libya?

----

16. In your opinion, what is the solution to save the Dorcas gazelle from extinction?

----

17. Would you like to make any other comments, observations or recommendations?

This final section will help me to learn more about the respondents of this survey. Your answers will be grouped together with those of others and will not be individually identifiable. All information is confidential.

Please circle and fill in the correct information.

18. How old are you?

17 - 30	31 - 40	41 - 50	51 - 60	61 - 70	>70

19. What level of education have you completed?

a.	Uneducated	b.	Primary or High school	c.	University

20. The name of your region? ---------------------------------------

21. Which respondent category do you fall into (please circle the relevant letter):

a. Hunter or other individual interested in hunting

b. Interested individual who lives near to where Dorcas gazelles are found.

c. Conservation organisation or other individual interested in wildlife conservation

d. Other (please write) ---------------------------------------

THANK YOU very much for your time and participation

Appendix 5: In-country questionnaire 2016

University of Wolverhampton: Faculty of Science and Engineering

Dear respondent,

My name is Walid Algadafi and I am a PhD researcher at the University of Wolverhampton, UK, studying the Conservation Ecology of the Dorcas gazelle (*Gazella dorcas*) in North East Libya (Fig. 1). As part of my research I am undertaking a questionnaire based study exploring the current knowledge base of Dorcas gazelle populations, their threats and conservation management. This questionnaire is designed to study a sample of the Libyan community, to see the importance of this gazelle to the people of Libya, and also to find out the current distribution and numbers of Dorcas gazelle in Libya. I hope to understand the reasons that have led to the decline and endangered of this gazelle in Libyan territory. I would be very grateful if you could please cooperate with me, to gain scientific and accurate information, which can lead to safeguarding this gazelle in Libya (Fig. 2), which needs help and our protection.

This questionnaire is concerned with your understanding, views and opinions regarding this area of Libya and forms a significant part of the information leading to the final research outcomes. I would be very grateful if you could find the time to respond to these questions.

Thank you for completing this questionnaire about your feelings towards the wildlife, such as Dorcas gazelle, living in Libya. Your opinions about this animal are important and I greatly appreciate your time spent answering these questions thoughtfully. Whether your answers are positive, neutral or negative your views are very valuable to me, as we are trying to document the range of people's attitudes towards this species of gazelle. Your answers should represent your own opinions, not those of others. So, we encourage you to voice your opinions. Please answer all the questions, but do not take too long over this: it is not an exam!

Your individual responses will not be used for any purpose other than for this research and your response will be kept confidential. In completing the questionnaire, you are consenting for your data to be used in the study. Please feel free to express yourself as much as possible, and you are free to discontinue your involvement at any time.

Please return the completed questionnaire to me at W.Agadafi@wlv.ac.uk. If you have any questions, please contact me at this email address or call me on my mobile No: 0916393571.

Thank you for your participation,

Yours faithfully,

Walid Algadafi

Lecturer in the Department of Environmental Sciences and Wildlife Conservation. Omar AL Mukhtar University, Libya

PhD researcher at the University of Wolverhampton, UK

Questionnaire

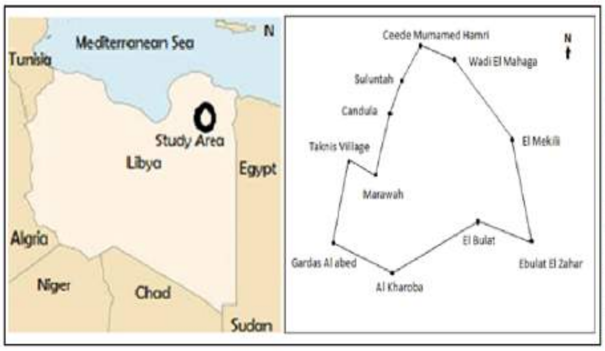


Fig. 1. General location of the study area in Libya and detail of the study area (South of the Green Mountain: approx. scale 300kmX300 km)

Fig. 2. The Dorcas gazelle

Gazelle are fast-moving graceful animals, with a beautiful shape. Dorcas gazelle are well-known in Libya and this has led to it becoming rare and endangered.

Knowledge, attitudes, distribution, and numbers of Dorcas gazelle

This section looks to establish estimates of the population numbers and distribution of Dorcas gazelle in North East Libya.

1. Have you ever seen the gazelle in the wild during the last year? *Please indicate your knowledge of the Dorcas gazelle*. Yes ( ) No ( )

If yes, please give me the places names and dates (where possible)?

----

2. What are the highest numbers of Dorcas gazelle that you have seen together during the last year? *Please circle the response that best describes your opinion*.

a	One gazelle	b	Two gazelles	c	Three gazelles	d	4 - 5 gazelles	e	Small groups. How many? ………..	F	Large herds. How many?	g	None

I would like to ask you some questions on how the Dorcas gazelle numbers may have changed over the last year in the area south of Green Mountain.

3. Do you think the numbers of Dorcas gazelle have changed or are staying the same?

Please circle the response that best describes your opinion.

a.	Increasing	b.	Decreasing	c.	Staying the same	d.	I don't know

4. What is your estimate of the decrease or increase of Dorcas gazelle numbers during the last year in areas where the gazelles have lived recently?

Please circle the response that best describes your opinion.

a.	Decrease	0 - 20 %	21 - 40 %	41 - 60 %	61 - 80 %	81 - 100 %
b.	Increase	0 - 20 %	21 - 40 %	41 - 60 %	61 - 80 %	81 - 100 %

Attitudes and threats to Dorcas gazelle and the reasons for these

This section explores the main issues that currently affect Dorcas gazelle populations in Libya.

5. Do you know of any new incidents in the last year (since August 2015) when Dorcas gazelle or other gazelle species have been killed in Libya? If so, please describe (a) which gazelle species; (b) the date in which it occurred; (c) where it occurred (name of place); (d) the method used to catch and kill the gazelle; (e) the number killed; and (f) the reason why they were killed. Enter the information in the table below (one line for each incident):

	Positions	Incident (1)	Incident (2)	Incident (3)
a.	Species			
b.	Date trapped			
c.	Location			
d.	Method used			
e.	Number			
F	Reason			

6. Would you like to make any other comments, observations or recommendations?

This final section will help me to learn more about the respondents of this survey. Your answers will be grouped together with those of others and will not be individually identifiable. All information is confidential.

Please circle and fill in the correct information.

7. How old are you?

17 - 30	31 - 40	41 - 50	51 - 60	61 - 70	>70

8. What level of education have you completed?

a.	Uneducated	b.	Primary or High school	c.	University

9. The name of your region? --

10. Which respondent category do you fall into (please circle the relevant letter):

a. Hunter or other individual interested in hunting

b. Interested individual who lives near to where Dorcas gazelles are found

c. Conservation organisation or other individual interested in wildlife conservation

d. Other (please write) --

THANK YOU very much for your time and participation

Appendix 6: Definition of the Chi-square Test and T-Test (Paired Samples Test)

Chi-square test:

According to Ankrah (2007) a chi-square (X^2) test is a non-parametric method that tabulates a variable into categories and calculates a X^2 statistic to test the hypothesis that the observed frequencies do not vary from their expected values.

The aim of applying a χ^2 is to test the variance between an actual sample and another hypothetical one (H_1). If the calculated value (χ^2) is smaller than the critical value (0.05), the hypothesis (H_1) is accepted if there is a statistically significant relationship between variables ($p<0.05$). While if the calculated p value is larger or even equal to the critical value ($p\geq0.05$), the null hypothesis (H_0) is accepted, so there is no relationship between variables. Mathematically, this relationship can be represented as the equation below showing the relationship between variables.

$$\boldsymbol{x^2} = \sum_i \frac{(Oi-Ei)^2}{Ei}$$

Where: O_i = the observed number of cases in category i (observed values), E_i = the expected number of cases in category i (expected values), and ∑ = summation.

T-Test (Paired Samples Test):

According to Siegle (2018), a *t* test is a type of inferential statistics which is used to identify if any difference between the means of two groups is statistically significant. In inferential statistics, it is assumed that dependent variables fit into a normal distribution pattern. This assumption allows the identification of the probability of any given outcome. An acceptable level of probability (*p*) must be identified before data is collected. The value most commonly used is $p < .05$. After the collection of data, a formula is used to calculate a test statistic. This is then compared with a critical value indicated on a table to decide if the results are within the acceptable level of probability. Computer programmes are used to calculate the test statistic and provide the exact probability of it being achievable with the number of subjects available. Among the most frequently used t-test is the Paired Samples Test (a paired difference test).

According to Fadem (2008), a paired difference test is a type of location test that is used when comparing two sets of measurements to assess whether their population means differ. A paired difference test uses additional information about the sample that is not present in an ordinary unpaired testing situation, either to increase the statistical power, or to reduce the effects of confounders.

According to Derrick *et al*. (2017), a location test is a statistical hypothesis test that compares the location parameter of a statistical population to a given constant, or that compares the location parameters of two statistical populations to each other. Most commonly, the location parameter of interest is expected values, but location tests based on medians or other measures of location are also used.

Appendix 7: Breakdown of gazelle sightings according to location, date, number of gazelles and number of respondents

Place names	Date	No. of individual gazelles sighted		Percentage of total sightings (%)		Average no. of sightings per respondent	No. of respondents (n=230)			
		2011-2015	2015-2016	2011-2015	2015-2016		2011-2015 (n=130)	2015-2016 (n=100)	2011-2015 (%)	2015-2016 (%)
Alkabar (Aljasha)	2012	4	-	25.2	-	2.83	1	-	0.77	-
		4	-				1	-	0.77	-
		5	-				1	-	0.77	-
	2013	3	-				1	-	0.77	-
		4	-				1	-	0.77	-
		4	-				1	-	0.77	-
	2014	3	-				1	-	0.77	-
		3	-				1	-	0.77	-
	2015	1	-				1	-	0.77	-
		3	-				1	-	0.77	-
		3	-				1	-	0.77	-
	2016	-	2	-	16.3		-	1	-	1
		-	1				-	1	-	1
		-	2				-	1	-	1
		-	2				-	1	-	1
		-	1				-	1	-	1
		-	3				-	1	-	1
		-	3				-	1	-	1
Alhasena (Aljasha)	2012	4	-	15.6	-	2.12	1	-	0.77	-
		3	-				1	-	0.77	-
	2013	3	-				1	-	0.77	-
		1	-				1	-	0.77	-
		2	-				1	-	0.77	-
	2014	3	-				1	-	0.77	-
		1	-				1	-	0.77	-
		1	-				1	-	0.77	-
	2015	3	-				1	-	0.77	-
		2	-				1	-	0.77	-
	2016	-	3	-	12.7		-	1	-	1
		-	1				-	1	-	1
		-	1				-	1	-	1
		-	2				-	1	-	1
		-	2				-	1	-	1
		-	2				-	1	-	1
Bosfia (Aljasha)	2011	5	-	10.9	-	2.87	1	-	0.77	-
	2012	3	-				1	-	0.77	-
	2013	3	-				1	-	0.77	-
	2014	2	-				1	-	0.77	-
		3	-				1	-	0.77	-
	2016	-	2	-	8.1		-	1	-	1
		-	2				-	1	-	1
		-	3				-	1	-	1
South west Gardas (Aljasha)	2015	1	-	10.2	-	2.22	1	-	0.77	-
		2	-				1	-	0.77	-
		3	-				1	-	0.77	-
		2	-				1	-	0.77	-
		3	-				1	-	0.77	-
		3	-				1	-	0.77	-
		1	-				1	-	0.77	-
	2016	-	3	-	5.8		-	1	-	1
		-	2				-	1	-	1
Thahar Hamala (Aljasha)	2013	3	-	6.8	-	2.6	1	-	0.77	-
	2014	4	-				1	-	0.77	-
		3	-				1	-	0.77	-
	2016	-	2	-	3.5		-	1	-	1
		-	1				-	1	-	1

South of Mrawah (Aljasha)	2012	3	-	6.8	-	3.25	1	-	0.77	-
		4	-				1	-	0.77	-
		3	-				1	-	0.77	-
	2016	-	3	-	3.5		-	1	-	1
Al Akaer (Aljasha)	2013	3	-	6.1	-	2.4	1	-	0.77	-
	2014	2	-				1	-	0.77	-
		3	-				1	-	0.77	-
	2015	1	-				1	-	0.77	-
	2016	-	3	-	3.5		-	1	-	1
Alklaiat (Aljasha)	2013	3	-	4.8	-	3	1	-	0.77	-
		4	-				1	-	0.77	-
	2016	-	2	-	2.3		-	1	-	1
El Mekhili (Alsrwal)	2011	5	-	3.4	-	2.66	1	-	0.77	-
	2016	-	2	-	3.5		-	1	-	1
		-	1				-	1	-	1
Am Algazallan	2011	3	-	4.8	-	2.66	1	-	0.77	-
	2012	4	-				1	-	0.77	-
	2016	-	1	-	1.2		-	1	-	1
Wadi Alsfa (Aljasha)	2016	-	2	-	9.3	2	-	-	-	1
		-	1				-	1	-	1
		-	3				-	1	-	1
		-	2				-	1	-	1
South of Wadi Almahaga (Algasha)	2016	-	2	-	8.1	1.4	-	1	-	1
		-	2				-	1	-	1
		-	1				-	1	-	1
		-	1				-	1	-	1
		-	1				-	1	-	1
Bulat Borkaes (Albulat)	2014	2	-	3.4	-	2	1	-	0.77	-
		3	-				1	-	0.77	-
	2016	-	1	-	1.2		-	1	-	1
Wadi Alsafak (Aljasha)	1016	-	2	-	5.8	1.66	-	1	-	1
		-	2				-	1	-	1
		-	1				-	1	-	1
Althaepan (Alsrwal)	2016	-	1	-	5.8	1.66	-	1	-	1
		-	2				-	1	-	1
		-	2				-	1	-	1
Bulat Mahers (Albulat)	2016	-	1	-	4.7	2	-	1	-	1
		-	3				-	1	-	1
Tanamlow (Alsrwal)	2016	-	2	-	3.5	1.5	-	1	-	1
		-	1				-	1	-	1
Masos (Alsrwal)	2011	3	-	2.0	-	3	1	-	0.77	-
Bulat Alraml (Albulat)	2016	-	1	-	1.2	1	-	1	-	1
Total		~147	~86	100	100	42.83	51	47	39.2	47
		~233		100%			98		42.6%	

Appendix 8: Field sheet for summer survey 2015

Location/Area name _______ Survey point No _______ Survey sheet number________
Date_________ Time _______ General Habitat type _______ Weather _________

Gazelle dung

Transect direction NWSE	Position (distance along transect)	Type scattered/not scattered	Age category 1-6	Male/female/don't know	Number+size of pellets	With scale photo	DNA sample taken	Comment

Other signs of gazelle – position on transect

Transect direction NWSE	Position (distance along transect)	Skull Bones Hair Other	Male/female/don't know	Number + size	With scale photo	Way point number	DNA sample	Comment

Tracks

Transect direction NWSE	Position	Type	Estimated number of individual	Length of hoof	Width of hoof	Stride length	Orientation or direction of travel	Photo with Scale

Date_____Time ____Location/Areaname__________ GPS Coordinate/Location _______

Topography: Valley / Hill / Flat plain / etc __________ Human structures ____________

Dorcas gazelle

Photo: Yes / No

Number Adults _____ Number juveniles ___ Sex: M how many ____ / F how many _____

Behaviour _______________

Feeding / Resting / Walking / Sleeping

Habitat

Low vegetation, name ___ / Shrubs, name ____ height____ / Trees, name___ height___

Low vegetation, name ___ / Shrubs, name ____ height___ / Trees, name___ height____

Low vegetation, name ____ / Shrubs, name ___ height___ / Trees, name___height____

Substrate: Rock / Sand / Soil

Other animals

Species __________ Numbers __________

Species __________ Numbers __________

Species __________ Numbers __________

Other Comments

____

____

Appendix 9: Field sheet used to collect distance sampling data

Location/Area name _____ Survey sheet number ______ Random no. coordinate ___

Date ________ Time ______ Elevation/m ____ Weather (sunny, rainy, windy, cloudy)

Topography (valley, hill, flat plain).

Way point number ____ GPS Coordinate/location: Latitude N ____ Longitude E _____

General habitat type (steppe, Semi desert, desert).

Gazelle sighting-estimated number seen _________ Direction ________ (N, W, S, E).

Gazelle Behaviour (feeding, resting, walking, running, sleeping, on a shrub). Adult/ Juvenile/ Male/ Female/ Don't know.

Were animals hiding in the vegetation- if so what species of plants?

____

What were they eating? (plant species)

____

Associated Fauna:

Camel: _____ Houbara bustards (*Chlamydotis undulata*): _____ Sheep: _____ Goats: ______ Cows: ____ Jackals: _______ Other: _______________________________

Findings on transects:

Transect Direction (NWSE)	Position on transect (distance along transect) (m)	Perpendicular distance (cm)	Dung Skull Bones Hair Tracks Footprint	Dung scattered-not scattered	Decay state-Age category (1-6)	Number of pellets or footprint	Size of covered area (cm)	DNA sample taken	Photo with scale	Substrate (rock, sand, soil)

Associated Flora (Vegetation name/ Vegetation type): Shrub list- Recorded in 5m Transect band. Vegetation density (Low density, Medium density, High density)

Local name	Scientific name	Local name	Scientific name
Halab	*Periploca angustifolia*	Salof	*Rhamnus tripartita*
Kazah	*Pituranthos tortuosus*	Ratem	*Retama raetam*
Kartab	*Polygonum equisetiforme*	Rameth	*Haloxylon articulatum*
Methnan	*Thymelaea hirsuta*	Shbrek	*Sarcopoterium spinosum*
Cedar	*Ziziphus lotus*	Shkarh	*Matthiola longipetala*
Agram	*Anabasis artiwpata*	Kabbar	*Capparis spinosa*
Harmal	*Peganum harmala*	Gdare	*Rhus tripartita*
Zater	*Thymus capitatus*	Kataf	*Atriplex rosea*
Sheah	*Artemisia herba-alba*	Lsls	*Didymus bipinnatus*

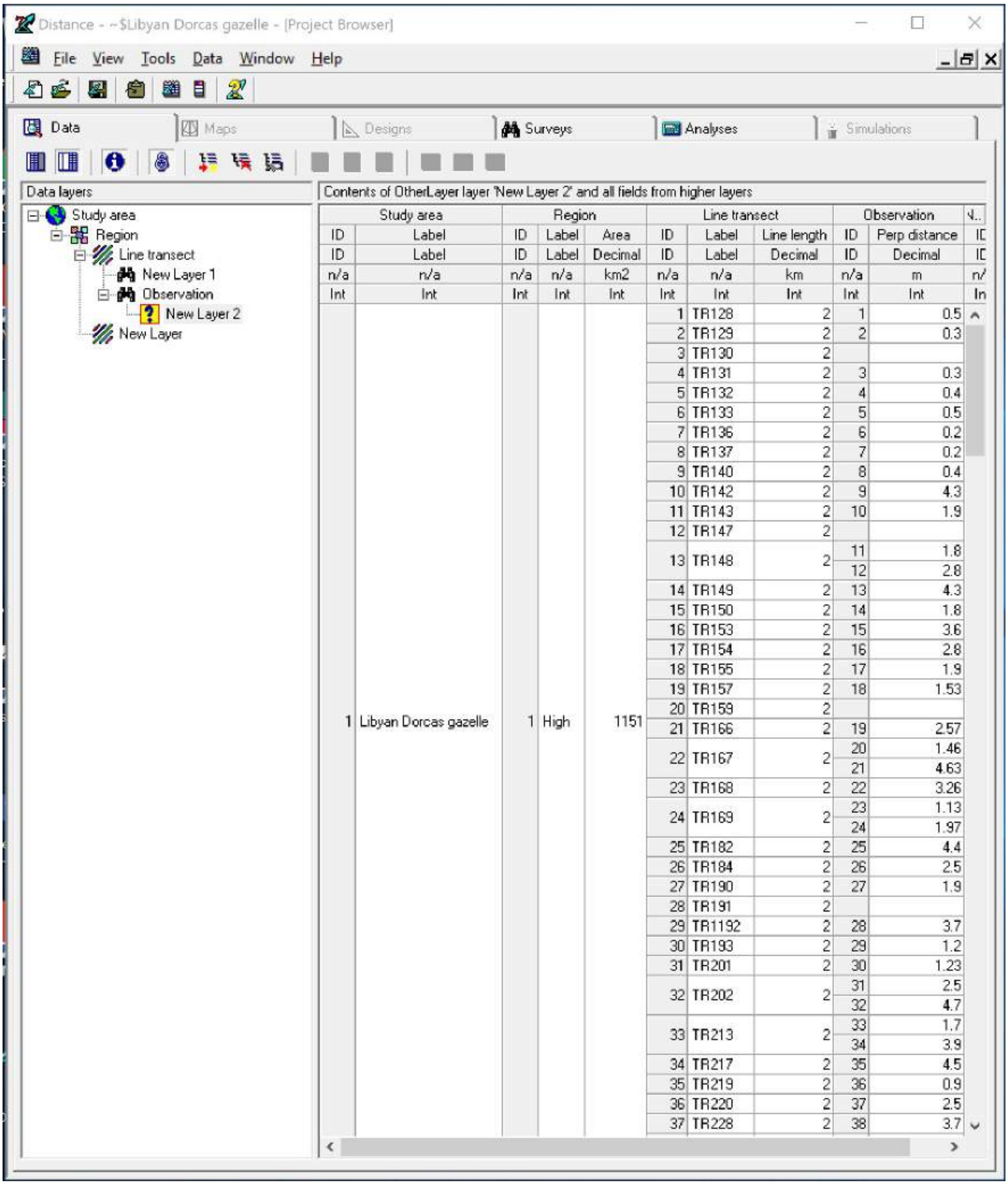
Other Comments:

……………………………………………………………………………………………………
……………………………………………………………………………………………………

Appendix 10: Field sheet used to observe decomposition rate (number of Dorcas gazelle dung remaining)

Visit Date	Decay rate (number of Dorcas gazelle dung remaining)									
	Habitat type									
	Rugged								Sandy	
	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5	
	No.	% (+/-)	No.	% (+/-)	No.	% (+/-)	No.	% (+/-)	No.	% (+/-)
22-25/09/2016	53	100	46	100	43	100	47	100	51	100
27/10/2016	53	100	46	100	43	100	47	100	51	100
27/11/2016	53	100	46	100	43	100	47	100	51	100
27/12/2016	50	-92.5 7.5	43	-91.3 8.7	39	-88.4 11.6	41	-85.1 14.9	43	-82.4 17.6
27/01/2017	46	-84.9 15.1	39	-82.6 17.4	37	-83.7 16.3	38	-78.7 21.3	41	-78.4 21.6
27/02/2017	40	-73.6 26.4	35	-73.9 26.1	32	-72.1 27.9	35	-72.2 27.8	40	-76.5 23.5
27/03/2017	31	-56.6 43.4	27	-56.5 43.5	30	-67.4 32.6	30	-61.7 38.3	38	-72.5 27.5
27/04/2017	25	-45.3 54.7	25	-52.2 47.8	24	-53.5 46.5	22	-44.7 55.3	23	-43.1 56.9
27/05/2017	20	-35.8 64.2	21	-43.5 57.5	19	-41.9 58.1	18	-36.2 63.8	19	-35.3 64.7
27/06/2017	17	-30.2 69.8	15	-30.4 69.6	15	-32.6 67.4	15	-29.8 70.2	12	-21.6 78.4
27/07/2017	13	-22.6 77.4	13	-26.1 73.9	11	-23.3 76.7	13	-25.5 74.5	3	-3.9 96.1
27/08/2017	7	-11.3 88.7	9	-17.4 82.6	7	-14 86	6	-10.6 89.4	0	-100 0

Appendix 11: Screenshot of part of the analysis of distance data imported into the DISTANCE 7.0 programme



Study area ID	Study area Label	Region ID	Region Label	Region Area	Line transect ID	Line transect Label	Line length	Observation ID	Perp distance
ID	Label	ID	Label	Decimal	ID	Label	Decimal	ID	Decimal
n/a	n/a	n/a	n/a	km2	n/a	n/a	km	n/a	m
Int	Int	Int	Int	Int	Int	Int	Int	Int	Int
1	Libyan Dorcas gazelle	1	High	1151	1	TR128	2	1	0.5
					2	TR129	2	2	0.3
					3	TR130	2		
					4	TR131	2	3	0.3
					5	TR132	2	4	0.4
					6	TR133	2	5	0.5
					7	TR136	2	6	0.2
					8	TR137	2	7	0.2
					9	TR140	2	8	0.4
					10	TR142	2	9	4.3
					11	TR143	2	10	1.9
					12	TR147	2		
					13	TR148	2	11	1.8
					13	TR148	2	12	2.8
					14	TR149	2	13	4.3
					15	TR150	2	14	1.8
					16	TR153	2	15	3.6
					17	TR154	2	16	2.8
					18	TR155	2	17	1.9
					19	TR157	2	18	1.53
					20	TR159	2		
					21	TR166	2	19	2.57
					22	TR167	2	20	1.46
					22	TR167	2	21	4.63
					23	TR168	2	22	3.26
					24	TR169	2	23	1.13
					24	TR169	2	24	1.97
					25	TR182	2	25	4.4
					26	TR184	2	26	2.5
					27	TR190	2	27	1.9
					28	TR191	2		
					29	TR1192	2	28	3.7
					30	TR193	2	29	1.2
					31	TR201	2	30	1.23
					32	TR202	2	31	2.5
					32	TR202	2	32	4.7
					33	TR213	2	33	1.7
					33	TR213	2	34	3.9
					34	TR217	2	35	4.5
					35	TR219	2	36	0.9
					36	TR220	2	37	2.5
					37	TR228	2	38	3.7

Appendix 12: GenBank accession numbers for the 90 reference samples used in this study

Species	GenBank accession numbers					
Gazella dorcas	JF728768	JN410233	JN410221	JN410225	JN410231	JN410232
	JN410318	JN410319	JN410219	JN410222	JN410226	JN410227
	JN410229	JN410230	JN410245	JN410250	JN410251	JN410316
	JN410333	JN410334	KC188752	JN410256	JN410338	JN410339
	JQ676941	JQ676951	JN410241	JN410325	JN410336	JN410337
	JQ676946	JN410234	JN410235	JN410237	JN410239	JN410240
	JN410247	JN410249	JN410238	JN410244	JN410248	JN410326
	JN410332	JN410220	JN410223	JN410315	JN410252	JN410253
	JN410254	JN410314	JN410316	JN410236	JN410243	JN410246
	JN410250	JN410251	JN410335	JN410255	JN410257	JQ676942
	JQ676943	JQ676944	JQ676945	JQ676947	JQ676948	JQ676949
	JQ676950		JQ676952		JN410258	
Gazella gazella	JN410260	JN410352	JN410261	JN410355	JN410356	JN410348
	JN410349	JN410350	JN410351	JN410353	JN410354	
Gazella leptoceros	JN410259	JN410344	JN410345	JN410346	JN410347	
Gazella bennettii	JN410340		JN410357		JN410341	
Gazella cuvieri	JN410342			JN410343		

Appendix 13: The sequences of samples obtained


Data Edit Search Alignment Web Sequencer Display Help
DNA Sequences
Translated Protein Sequences
Species/Abbrv
Group Name
1. DDRG001_F_AND_R
2. DRG002_F_AND_R
3. DRG003_F_AND_R
4. DRG006_F_AND_R
5. DRG010_F_AND_R
6. DRG011_F_AND_R
7. DRG015_F_AND_R
8. DRG018_F_AND_R
9. DRG020_F_AND_R
10. DRG021_F_AND_R
11. DRG024_F_AND_R
12. DRG041_F_AND_R
13. DRG043_F_AND_R
14. DRG050_F_AND_R
15. DRG052_F_AND_R
16. DRG053_F_AND_R
17. DRG012_F_AND_R
18. DRG047_F_AND_R
19. DRG054_F_AND_R
20. DRG055_F_AND_R
21. DRG056_F_AND_R
Site # 597
with
w/o Gaps

Appendix 14: Summary and critical assessment of the research findings

Research question 1. What is the estimated abundance of Dorcas gazelle in the study area?					
Evidence from local stakeholder survey in Libya	**Evidence from the international experts' survey**	**Evidence from the field work survey**	**Evidence from the DNA genetic analysis**	**Findings from the literature review**	**Critical assessment of the findings**
The data suggested that about 233 individuals are thought to exist in the study area.	All respondents stated that it is now impossible to estimate the total population size and they were not able to give an estimate as no systematic surveys had been conducted. The evidence of the respondents about distribution, coupled with the supporting indications from social media, would suggest that, the gazelle groups tended to be extremely small.	From a distance sampling survey based on indirect signs, the data suggested an estimated population of Dorcas gazelle in the study area of 1070 individuals.	No evidence	No systematic surveys have been carried out in this area to establish the exact distribution and/or to make specific estimates of Dorcas gazelle populations. Thus, no quantitative data are available for the species in Libya. According to Scholte and Hashim (2013), the population in Libya is unlikely to exceed 1000 individuals. Elsewhere, Wacher and Newby (2010) have estimated about 8761 individuals of Dorcas gazelle in Chad by distance sampling method.	No previous quantitative estimate of the abundance of Dorcas gazelle in Libya or in the study area is available and no systematic surveys had been carried out on which to base any estimates. This study applied two methods (Questionnaire and Distance Sampling methodology) in an attempt to estimate the abundance of Dorcas gazelle. Other studies using Distance Sampling methodology (Marques *et al*. 2001) have not established comparisons with other methods, thus the relative accuracy of this method cannot be absolutely confirmed. Methods outlined in this study can be used to estimate gazelle abundance, but their accuracy can not be estimated since the true population size is unknown in the study area. Here the first statistically contrasted assessment, there was a 78.3% difference between the estimated population figure obtained through the field survey and the number reported by the respondents. Population estimation methods were not standardised. This may make it difficult to obtain reliable estimates of this population. To understand this inconsistency, future surveys should be conducted to complete the validation of both methods. However, this study produced the first contemporary estimates of wild Dorcas gazelle in the study area and provides a foundation for further studies on the distribution and abundance of this gazelle within Libya, which is a necessary first step in any conservation effort.
Research question 2. Has the recent war in Libya (beginning in 2011) contributed to a decline in the population of the Dorcas gazelle in North East Libya?					
Evidence from local stakeholder survey in Libya	**Evidence from the international experts' survey**	**Evidence from the field work survey**	**Evidence from the DNA genetic analysis**	**Findings from the literature review**	**Critical assessment of the findings**
100% of the respondents strongly agreed, or agreed, that the recent war in Libya in 2011 has led to low numbers and the decrease of Dorcas gazelle.	100% of expert respondents reported that entire herds have been exterminated during the recent war in Libya and this continues to be very serious.	Evidence of hunting was found in the form of caches of freshly-butchered remains and vehicle tracks were a sign of larger scale hunting.	No evidence	Conflict and social insecurity are known to accelerate biodiversity decline globally and escalate illegal killing of wildlife (Douglas and Alie, 2014; Gaynor *et al*. 2016). According to SCF (2012), the 'Arab Spring' led to a massacre of wildlife in all areas and had a particularly negative impact on the Dorcas gazelle in Libya, although they provide no specific figures. Zedany and Al-Kich, (2013) state that poaching was reasonably well managed by Gaddafi's regime but has	Analyses of the various sources clearly show an association between population decline for Dorcas gazelle and the beginning of the conflict in Libya. This decline has also been replicated in the study area. The research findings agree with those of SCF (2012 and 2015); Zedany and Al-Kich (2013); Douglas and Alie (2014); Gaynor *et al*. (2016) and Brito *et al*. (2018), where the conflict and social insecurity are known to accelerate biodiversity decline globally and escalate illegal killing of wildlife. However, the conflict is not considered the main factor in the decline. Specifically, the data collected from the in-country questionnaires suggest that illegal killings accelerated one to five years after armed conflicts ignited in Libya (Fig. 4.8). The findings completely accord with Khattabi and Mallon (2001) that a better enforcement of the legislation

				since risen significantly, although again they produce no statistics. Brito *et al*. (2018) reported that the number of Dorcas gazelles illegally killed in Libya increased after 2011, with killing events widespread across the country.	in the 1990s contributed to some improvement and more game species being observed in several parts of Libya. The results of this study show that there was a decrease in numbers of gazelle killed during this period. The results also agree with both SCF (2012) and Brito *et al*. (2018) with regard to enforcement becoming more complicated since the war in Libya in 2011 leading to extremely high numbers of animals have been killed. By contrast there is some indication from respondents that there is a decline in gazelle killings since 2016.
Research question 3. Does a lack of environmental awareness by and the general behaviour of local residents lead to practices that endanger the Dorcas gazelle?					
Evidence from local stakeholder survey in Libya	**Evidence from the international experts' survey**	**Evidence from the field work survey**	**Evidence from the DNA genetic analysis**	**Findings from the literature review**	**Critical assessment of the findings**
The results showed that there was a lack of environmental awareness and a lack of community education in the local communities. The results indicate that 95.4% of respondents strongly agreed or agreed that a lack of environmental awareness of the value of gazelle has led to low numbers and a decrease in the population of the Dorcas gazelle. 98.5% of respondents strongly agreed or agreed that communities and hunters, needed more information and awareness about the value of the gazelle.	No evidence. However, 92.3% of experts reported that the environmental awareness programmes for local people should be an element in any conservation programme.	No evidence	No evidence	According to Zedany and Al-Kich (2013), hunters hunt for sport and pleasure rather than necessity and frequently underestimate the devastation they cause to wildlife. Brito *et al*. (2018) discussed the importance of ingraining a culture of environmental responsibility among all stakeholders and fostering environmental awareness to drive societal change. Sillero-Zubiri *et al*. (2013) argued that effective anti-hunting strategies must be accompanied be education programmes.	The findings from the three sources indicate that a lack of environmental awareness has had a negative effect on Dorcas gazelle populations. This factor is considered the most important issue affecting the survival of Dorcas gazelle in the study area because it encompasses and leads to other negative influencing factors. Therefore, if this factor can be addressed and human behaviour towards wildlife improved, it is likely all other factors contributing to the decline of the Dorcas gazelle will be reduced. This may also lead to an acceptance that poaching should be stopped urgently. This factor has led to success and exceeded the objectives of the reintroduction project maintaining of Dorcas gazelle populations in Senegal (Fernández-Bellon *et al*. 2018). Therefore, increasing awareness through education programmes may lead to increased protection for the gazelle in Libya.
Research question 4. Is the population of Dorcas gazelle in the study area genetically distinctive?					
Evidence from local stakeholder survey in Libya	**Evidence from the international experts' survey**	**Evidence from the field work survey**	**Evidence from the DNA genetic analysis**	**Findings from the literature review**	**Critical assessment of the findings**
No evidence	No evidence	No evidence	The genetic analysis of the sampled Dorcas gazelle population from North East Libya found eight haplotypes, four of which clustered closely with other African Dorcas gazelle populations and four which have not been identified elsewhere.	No previous studies have attempted to investigate the genetic profile of Dorcas gazelle in Libya. Lerp *et al*. (2011) recommended that ideally sequences from Libya should be included in future analyses. Overall, according to Lerp *et al*. (2011) and Godinho *et al*. (2012), the various analyses using mitochondrial DNA samples indicate that the Dorcas gazelle comprise one population.	The findings of this study indicate that the genetic diversity of Dorcas gazelle from North East Libya was higher than expected and is unique. This suggests that, at present, there is no major risk of a genetic bottleneck and most likely results from mixed ancestry and intracontinental translocation of animals. Furthermore, the decrease in the population does not indicate a loss of genetic diversity. The results of this study are consistent with Lerp *et al*. (2011) and Godinho *et al*. (2012) in that the combined dataset for Dorcas gazelle shows that this species still has appreciable levels of mtDNA genetic diversity.

Research question 5. What are the elements of a suitable management strategy that will have a positive impact on the conservation of Dorcas gazelle in NE Libya?					
Evidence from local stakeholder survey in Libya	**Evidence from the international experts' survey**	**Evidence from the field work survey**	**Evidence from the DNA genetic analysis**	**Findings from the literature review**	**Critical assessment of the findings**
The respondents' opinions indicate that there is strong agreement up to 100% on a whole host of conservation measures for the Dorcas gazelle in the study area.	All believed that, in the current context of unrest and increasing hunting, captive breeding in different places in Libya may be a good solution until better conditions prevail. 92.3% of respondents stated that the environmental awareness of local people should be increased. 84.6% of respondents believed that it is an important prerequisite for conservation that political stability, a functioning administration and physical security should be established. They saw little chance of this without outside intervention and the help of local and civil society.	No evidence	Gilbert (2011) stated that it is vital that sustaining genetic diversity and demographic stability should be the guiding principles in the management of antelope populations. According to Frankham (2010), species that are endangered usually have a lower degree of genetic variation. Briscoe *et al*. (1992) have suggested that a large population alone may not be sufficient to preserve genetic variation. Franklin (1980) suggested that a minimum, effective number to eliminate the impact of inbreeding in the short term is 50 individuals, with a long-term target of 500 so that mutation can be counter-balanced by drift and evolutionary potential protected.	Newby *et al*. (2016) noted that the range of challenges which antelope face in the Sahelo-Saharan region requires the adoption of a conservation approach that will link the captive, semi-captive, and wild populations across the world. In this way, the IUCN's Conservation Breeding Specialist Group support an integrated, 'One Plan' approach to conservation planning, which considers all populations of the species, inside and outside their natural range, under all conditions of management, engaging all responsible parties and all available resources from the very start of any species conservation planning initiative (Byers *et al*. 2013), which includes captive breeding, habitat restoration and reintroduction programmes.	Overall, seven intervention strategies were identified: declaration of the study area as a protected area, protection laws, awareness-raising and valourisation, research and monitoring, supplementary feeding, captive breeding and management *in situ* and *ex situ*, and international cooperation. Each of these supported by short-, medium- and long-term activities. Elements of this strategy have been adopted from some strategic programmes on gazelle from other countries such as Tunisia, Morocco, Algeria and Senegal (SSIG, 2002; Abaigar *et al*. 2018; IUCN, 2018). However, the success of this particular strategy would be closely linked to the work by several stakeholders at different levels where each one must act in collaboration with various institutions in order to accomplish these objectives effectively. Protected areas together with local community engagement in conservation are key tools in securing the survival of Dorcas gazelle, and regional peace and stability at the local level. The findings of this study agree with Geldmann *et al*. (2013) that protected areas are essential, but the success of such as these areas will be more effective via local stakeholders and may open up opportunities for species conservation in other areas. However, the results and success of this proposed strategy can be compared only after implementation of the programme in Libya.

Appendix 15: Elements of a breeding programme

Appendix 15. Actions for the establishment of a breeding programme for Dorcas gazelle in Libya (adapted from Olds, 2014)

1.	Establishment of a recovery team	Expert stakeholders, including scientists and other relevant parties, come together to form a Recovery Team and prepare a Recovery Plan for approval.
2.	Stakeholder engagement	A conservation programme will require a diversity of stakeholders, all of which need to be engaged as far as possible.
3.	Secure approvals, permits, funding and resources	A conservation programme will require investment and ongoing funding to maintain it.
4.	Identification of potential source populations	Surveys and scientific evaluation to assess Dorcas gazelle populations. Multipurpose, comprehensive recovery actions, including the feasibility of relocation, need to be considered.
5.	Genetic assessment	The wild population of Dorcas gazelle is known to be declining. The length of the programme and amount of genetic diversity required to be determined.
6.	Enclosure design	Considerable planning will be required.
7.	Facility construction	Ensuring facilities are suitable. Ample time needs to be given for facility construction.
8.	Catch and transfer	Several transfers may be required initially and throughout the programme of Dorcas gazelle from the wild. The collection of Dorcas gazelle should not jeopardise source populations through overharvesting or by leaving dysfunctional social groups.
9.	Monitoring and observation	Time will be required for the gazelle to settle in and acclimatise. Their behaviour and feeding should be closely monitored.
10.	Quarantine	Thirty days quarantine is required.
11.	Institutions and population management	Establishment of a studbook and institutional agreements.
12.	Population growth	Population should be grown as quickly as possible. Rare alleles to be maintained.
13.	Population maintenance	The population should be maintained at a size where individuals can be removed for reintroduction without affecting the captive source population.
14.	Monitoring of sex ratios	The Dorcas gazelle is considered to be polygamous, so a founding population of sex ratio of 5:1 in favour of females is desirable.